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(54) Title: SYNTHETIC ANTIBODY PHAGE LIBRARIES

(57) Abstract: The invention provides comprising variant amino acids in CDRs of antibody variable domains. These polypeptides provide a source of great sequence diversity that can be used as a source for identifying novel antigen binding polypeptides. The invention also provides these polypeptides as fusion polypeptides to heterologous polypeptides such as at least a portion of phage or viral coat proteins, tags, and linkers. Libraries comprising a plurality of these polypeptides are also provided. In addition, methods of and compositions for generating and using these polypeptides and libraries are provided.

## SYNTHETIC ANTIBODY PHAGE LIBRARIES

### FIELD OF THE INVENTION

5           The invention generally relates to libraries of antibodies or antibody variable domains. The libraries include a plurality of different antibody variable domains generated by creating diversity in the CDR regions. In particular, diversity in CDR regions is designed to maximize the diversity while minimizing the structural perturbations of the antibody variable domain. The invention also relates to fusion polypeptides of one or more antibody variable domain and a heterologous protein such as a coat protein of a virus. The invention also relates to replicable expression vectors which include a gene encoding the fusion polypeptide, host cells containing the expression vectors, a virus which displays the fusion polypeptide on the surface of the virus, libraries of the virus displaying a plurality of different fusion polypeptides on the surface of the virus and methods of using those compositions. The methods and compositions of the invention are useful for identifying novel antibodies that can be used therapeutically or as reagents.

### BACKGROUND

20           Phage display technology has provided a powerful tool for generating and selecting novel proteins that bind to a ligand, such as an antigen. Using the techniques of phage display allows the generation of large libraries of protein variants that can be rapidly sorted for those sequences that bind to a target antigen with high affinity. Nucleic acids encoding variant polypeptides are fused to a nucleic acid sequence encoding a viral coat protein, such as the gene III protein or the gene VIII protein. Monovalent phage display systems where the nucleic acid sequence encoding the protein or polypeptide is fused to a nucleic acid sequence encoding a portion of the gene III protein have been developed. (Bass, S., *Proteins*, 8:309 (1990); Lowman and Wells, *Methods: A Companion to Methods in Enzymology*, 3:205 (1991)). In a monovalent phage display system, the gene fusion is expressed at low levels and wild type gene III proteins are also expressed so that infectivity of the particles is retained. Methods of generating peptide libraries and screening those libraries have been disclosed in many patents (e.g. U.S. Patent No. 5,723,286, U.S. Patent No. 5,432, 018, U.S. Patent No. 5,580,717, U.S. Patent No. 5,427,908 and U.S. Patent No. 5,498,530).

The demonstration of expression of peptides on the surface of filamentous phage and the expression of functional antibody fragments in the periplasm of *E. coli* was important in the development of antibody phage display libraries. (Smith et al., Science (1985), 228:1315; Skerra and Pluckthun, Science (1988), 240:1038).

5 Libraries of antibodies or antigen binding polypeptides have been prepared in a number of ways including by altering a single gene by inserting random DNA sequences or by cloning a family of related genes. Methods for displaying antibodies or antigen binding fragments using phage display have been described in U.S. Patent Nos. 5,750,373, 5,733,743, 5,837,242, 5,969,108, 6,172,197, 5,580,717,  
10 and 5,658,727. The library is then screened for expression of antibodies or antigen binding proteins with desired characteristics.

Phage display technology has several advantages over conventional hybridoma and recombinant methods for preparing antibodies with the desired characteristics. This technology allows the development of large libraries of  
15 antibodies with diverse sequences in less time and without the use of animals. Preparation of hybridomas or preparation of humanized antibodies can easily require several months of preparation. In addition, since no immunization is required, phage antibody libraries can be generated for antigens which are toxic or have low antigenicity (Hogenboom, Immunotechniques (1988), 4:1-20). Phage antibody  
20 libraries can also be used to generate and identify novel human antibodies.

Human antibodies have become very useful as therapeutic agents for a wide variety of conditions. For example, humanized antibodies to HER-2, a tumor antigen, are useful in the diagnosis and treatment of cancer. Other antibodies, such as anti-INF- $\gamma$  antibody, are useful in treating inflammatory conditions such as  
25 Crohn's disease. Phage display libraries have been used to generate human antibodies from immunized, non-immunized humans, germ line sequences, or naïve B cell Ig repertoires (Barbas & Burton, Trends Biotech (1996), 14:230; Griffiths et al., EMBO J. (1994), 13:3245; Vaughan et al., Nat. Biotech. (1996), 14:309; Winter EP 0368 684 B1). Naïve, or nonimmune, antigen binding libraries have been  
30 generated using a variety of lymphoidal tissues. Some of these libraries are commercially available, such as those developed by Cambridge Antibody Technology and Morphosys (Vaughan et al., Nature Biotech 14:309 (1996); Knappik et al., J. Mol. Biol. 296:57 (1999)). However, many of these libraries have limited diversity.

The ability to identify and isolate high affinity antibodies from a phage display library is important in isolating novel human antibodies for therapeutic use. Isolation of high affinity antibodies from a library is dependent on the size of the library, the efficiency of production in bacterial cells and the diversity of the library.

5 See, for e.g., Knappik et al., *J. Mol. Biol.* (1999), 296:57. The size of the library is decreased by inefficiency of production due to improper folding of the antibody or antigen binding protein and the presence of stop codons. Expression in bacterial cells can be inhibited if the antibody or antigen binding domain is not properly folded. Expression can be improved by mutating residues in turns at the surface of  
10 the variable/constant interface, or at selected CDR residues. (Deng et al., *J. Biol. Chem.* (1994), 269:9533, Ulrich et al., *PNAS* (1995), 92:11907-11911; Forsberg et al., *J. Biol. Chem.* (1997), 272 :12430). The sequence of the framework region is a factor in providing for proper folding when antibody phage libraries are produced in bacterial cells.

15 Generating a diverse library of antibodies or antigen binding proteins is also important to isolation of high affinity antibodies. Libraries with diversification in limited CDRs have been generated using a variety of approaches. See, for e.g., Tomlinson, *Nature Biotech.* (2000), 18:989-994. CDR3 regions are of interest in part because they often are found to participate in antigen binding. CDR3 regions  
20 on the heavy chain vary greatly in size, sequence and structural conformation.

Others have also generated diversity by randomizing CDR regions of the variable heavy and light chains using all 20 amino acids at each position. It was thought that using all 20 amino acids would result in a large diversity of sequences of variant antibodies and increase the chance of identifying novel antibodies.

25 (Barbas, *PNAS* 91:3809 (1994); Yelton, DE, *J. Immunology*, 155:1994 (1995); Jackson, J.R., *J. Immunology*, 154:3310 (1995) and Hawkins, RE, *J. Mol. Biology*, 226:889 (1992)).

There have also been attempts to create diversity by restricting the group of amino acid substitutions in some CDRs to reflect the amino acid distribution in  
30 naturally occurring antibodies. See, Garrard & Henner, *Gene* (1993), 128:103; Knappik et al., *J. Mol. Biol.* (1999), 296:57. However, these attempts have had varying success and have not been applied in a systematic and quantitative manner. Creating diversity in the CDR regions while minimizing the number of amino acid changes has been a challenge.



There is a need to isolate novel high affinity antibodies for clinical uses, for example therapeutic and diagnostic uses. To meet this need, there remains a need to generate a highly diverse library of antibody variable domains that can be expressed in high yield in cells. The invention described herein meets this need and provides  
5 other benefits.

### SUMMARY OF INVENTION

The present invention provides methods of systematically and efficiently generating polypeptides comprising diversified CDRs. In one embodiment, the  
10 invention provides rapid identification of high affinity binders to target antigens that can also be readily produced in high yield in cell culture. Unlike conventional methods that propose that adequate diversity of target binders can be generated only if a particular CDR(s), or all CDRs should be diversified, and unlike conventional notions that adequate diversity is dependent upon the broadest range of amino acid  
15 substitutions (generally by substitution using all or most of the 20 amino acids), the invention provides methods capable of generating high quality target binders that are not necessarily dependent upon diversifying a particular CDR(s) or a particular number of CDRs of a reference polypeptide or source antibody. The invention is based, at least in part, on the surprising and unexpected finding that highly diverse  
20 libraries of high quality can be generated by systematic and selective substitution of a minimal number of amino acid positions with a minimal number of amino acid residues. Methods of the invention are convenient, based on objective and systematic criteria, and rapid. Candidate binder polypeptides generated by the invention possess high-quality target binding characteristics and have structural  
25 characteristics that provide for high yield of production in cell culture. The invention also provides unique dimerization/multimerization techniques that further enhance library characteristics, and the binding characteristics of candidate fusion polypeptide binders therein.

In particular, fusion polypeptides comprising diversified CDR(s) and a  
30 heterologous polypeptide sequence (preferably that of at least a portion of a viral polypeptide) are generated, individually and as a plurality of unique individual polypeptides that are candidate binders to targets of interest. Compositions (such as libraries) comprising such polypeptides find use in a variety of applications, in particular as large and diverse pools of candidate immunoglobulin polypeptides (in

particular, antibodies and antibody fragments) that bind to targets of interest. The invention encompasses various aspects, including polypeptides generated according to methods of the invention, and systems, kits and articles of manufacture for practicing methods of the invention, and/or using polypeptides and/or compositions of the invention.

In another aspect, the invention provides methods of generating a polypeptide and polypeptides comprising at least one, two, three, four or all variant CDRs (i.e., selected from the group consisting of CDRs L1, L2, L3, H1 and H2 wherein said polypeptide is capable of binding a target antigen of interest, and wherein said CDR is not CDRH3, said method comprising: (a) identifying at least one (or any number up to all) solvent accessible and highly diverse amino acid position in a CDR; and (b) replacing the amino acid at the solvent accessible and high diverse position with a target amino acid (as defined herein) by generating variant copies of the CDR using a non-random codon set, wherein at least about 50%, 60%, 70%, 80%, 90% or all of the amino acids encoded by the non-random codon set are target amino acids (as defined herein) for that position in known antibody and/or naturally occurring variable domains.

In another aspect, the invention provides a method of generating a polypeptide comprising at least one, two, three, four, five or all of variant CDRs selected from the group consisting of H1, H2, H3, L1, L2 and L3, wherein said polypeptide is capable of binding a target antigen of interest, said method comprising: (a) with respect to L1, L2, L3, H1 and H2, (i) identifying at least one (or any number up to all) solvent accessible and highly diverse amino acid position in a reference CDR corresponding to the variant CDR; and (ii) replacing the amino acid at the solvent accessible and high diverse position with a target amino acid by generating variant copies of the CDR using a non-random codon set, wherein at least about 50%, 60%, 70%, 80%, 90% or all of the amino acids encoded by the non-random codon set are target amino acids for that position in known antibodies or antigen binding fragments(e.g. antibody variable domains)); and (b) with respect to H3, replacing at least one (or any number up to all) position with a variant amino acid.

In another aspect, the invention provides a method of generating a polypeptide comprising at least one, two, three, four, five or all of variant CDRs selected from the group consisting of L1, L2, L3, H1, H2 and H3, said method

comprising: (a) substituting at least one (or any number up to all) solvent accessible and highly diverse amino acid position in L1, L2, L3, H1 and/or H2 with a variant amino acid which is encoded by a nonrandom codon set, wherein at least 50%, 60%, 70%, 80%, 90% or all of amino acids encoded by the nonrandom codon set are target amino acids for said amino acid position in known antibodies or antigen binding fragments; and (b) substituting at least one (or any number up to all) amino acid position in H3 with a variant amino acid.

Various aspects and embodiments of methods of the invention are useful for generating and/or using a pool comprising a plurality of polypeptides of the invention, in particular for selecting and identifying candidate binders to target antigens of interest. For example, the invention provides a method of generating a composition comprising a plurality of polypeptides, each polypeptide comprising at least one, two, three, four, five or all of variant CDRs selected from the group consisting of L1, L2, L3, H1, H2 and H3, said method comprising: (a) substituting at least one (or any number up to all) solvent accessible and highly diverse amino acid position in L1, L2, L3, H1 and/or H2 with a variant amino acid which is encoded by a nonrandom codon set, wherein at least 50%, 60%, 70%, 80%, 90% or all of amino acids encoded by the nonrandom codon set are target amino acids for said amino acid position in known antibodies or antigen binding fragments; and/or (b) substituting at least one (or any number up to all) amino acid position in H3 with a variant amino acid; wherein a plurality of polypeptides are generated by amplifying a template polynucleotide with a set of oligonucleotides comprising degeneracy in the sequence encoding a variant amino acid, wherein said degeneracy reflects the multiple codon sequences of the nonrandom codon set.

In another example, the invention provides a method comprising: constructing an expression vector comprising a polynucleotide sequence which encodes a light chain, a heavy chain, or both, the light chain and the heavy chain variable domains of a source antibody comprising at least one, two, three, four, five or all CDRs selected from the group consisting of CDR L1, L2, L3, H1, H2 and H3; and mutating at least one, two, three, four, five or all CDRs of the source antibody at at least one (or any number up to all) solvent accessible and highly diverse amino acid position using a nonrandom codon set, wherein at least about 50%, 60%, 70%, 80%, 90% or all of the amino acids encoded by the non-random codon set are target

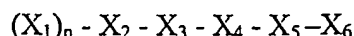
amino acids for that position in known and/or naturally occurring antibodies or antigen binding fragments (for e.g. antibody variable domains).

In another example, the invention provides a method comprising:  
constructing a library of phage or phagemid particles displaying a plurality of  
5 polypeptides of the invention; contacting the library of particles with a target antigen  
under conditions suitable for binding of the particles to the target antigen; and  
separating the particles that bind from those that do not bind to the target antigen.

In any of the methods of the invention described herein, a solvent accessible  
and/or highly diverse amino acid position can be any that meet the criteria as  
10 described herein, in particular any combination of the positions as described herein,  
for example any combination of the positions described for the polypeptides of the  
invention (as described in greater detail below). Suitable variant amino acids can be  
any that meet the criteria as described herein, for example variant amino acids in  
polypeptides of the invention as described in greater detail below.

15 Designing diversity in CDRH3 regions involves designing diversity in the  
length (preferably 7 to 19 amino acids) and/or in the sequence of CDRH3. In some  
embodiments, a portion of CDRH3 has a length ranging from 4 to 14 amino acids  
and has a variant amino acid at one or more positions encoded by codon sets that  
20 encode amino acids found in CDRH3 regions in known and/or naturally occurring  
antibody variable domains such as *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or mixtures thereof  
and another portion of the CDR, preferably at the C terminal end (e.g amino acid  
positions  $X_2$ ,  $X_3$ ,  $X_4$ ,  $X_5$  and  $X_6$  shown below), has much more limited diversity. In  
some embodiments, the C terminal end has an amino acid sequence YAMDY or  
FDY.

25 One aspect of the invention provides a polypeptide, such as an antibody  
variable domain, comprising a variant CDRH3 that comprises an amino acid  
sequence:



wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*,  
30 *NNS*, *DVK*, *NVT*, *XYZ* or is tryptophan or glycine or mixtures thereof, and  $n = 4$  to  
14;

$X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*,  
*DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine, phenylalanine, serine,  
alanine, glycine, leucine, or tryptophan;

$X_3$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is alanine, valine, aspartic acid or glycine;

$X_4$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is methionine;

5  $X_5$  is aspartic acid, alanine, valine, or glycine; and

$X_6$  is tyrosine or valine.

A polypeptide or library of polypeptides with variant CDRH3 of the formula as shown above may be generated using any one or combination of the oligonucleotides illustrated in Figure 4 and Figure 43.

10 In one embodiment, CDRH3 comprises an amino acid sequence  $(X_1)_n - X_2 - X_3 - X_4 - X_5 - X_6$ , wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;  $X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*, *DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine,  
15 phenylalanine, serine, glycine, alanine, leucine, or tryptophan;  $X_3$  is alanine, valine, aspartic acid or glycine;  $X_4$  is methionine;  $X_5$  is aspartic acid, alanine, valine, or glycine; and  $X_6$  is tyrosine or valine.

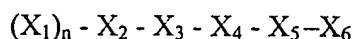
In some embodiments,  $n$  is preferably 4 and  $X_1$  is any naturally occurring amino acid encoded by codon sets *NNK*, *NNS* or *XYZ*,  $X_2$  is any naturally occurring  
20 amino acid encoded by *KSG*, *NNK*, *XYZ* or is tyrosine,  $X_3$  is alanine, glycine or valine,  $X_4$  is methionine,  $X_5$  is aspartic acid and  $X_6$  is tyrosine. A polypeptide or plurality of polypeptides comprising variant CDRH3 region in these embodiments can be generated using at least one or more than one of oligonucleotides F66e and F66f.

25 In some embodiments,  $n$  is preferably 6, and  $X_1$  is any naturally occurring amino acid encoded by codon sets *DVK*, *NVT*, *NNK*, *NNS* or *XYZ* or tryptophan or glycine or mixtures thereof.  $X_2$  is any naturally occurring amino acid encoded by *DSG*, *DVK*, *KSG*, *NNK*, *XYZ* or is tyrosine, glycine, serine, alanine or tryptophan,  $X_3$  is alanine,  $X_4$  is methionine,  $X_5$  is aspartic acid and  $X_6$  is tyrosine. In some  
30 embodiments,  $X_1$  corresponds to amino acid position 95,  $X_2$  corresponds to amino acid position 100a, A is in position 100b, M is in position 100c, D is in position 101 and Y is in position 102 of CDRH3 of antibody 4D5. A polypeptide or plurality of polypeptides comprising a variant CDRH3 region in these embodiments can be generated using at least one or more than one of oligonucleotides F63, F64, F65,

F66, F165, F134, F135, F163a, F166, F167, F66a, F66b, F66a1, F66b1, F190f, and F190n.

In another embodiment, CDRH3 comprises an amino acid sequence  $(X_1)_n - X_2 - X_3 - X_4 - X_5 - X_6$ ; wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or is tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;  $X_2$  is leucine or phenylalanine;  $X_3$  is missing;  $X_4$  is missing;  $X_5$  is aspartic acid, alanine, valine, or glycine; and  $X_6$  is tyrosine or valine. In some embodiments, the variant CDRH3 comprises an amino acid sequence  $(X_1)_n - X_2 - D - Y$ ; wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;  $X_2$  is leucine or phenylalanine; D is aspartic acid and Y is tyrosine. In other embodiments,  $n$  is preferably 6 and  $X_1$  corresponds to amino acid position 95,  $X_2$  corresponds to amino acid position 100a,  $X_5$  is in position 101 and  $X_6$  is in position 102 of CDRH3 of antibody 4D5. A polypeptide or plurality of polypeptides comprising a variant CDRH3 region in these embodiments can be generated using at least one or more than one of oligonucleotides F171c, F171d, F171e, F171, F185, F186, F187, F185a, F185b, F185b1, F187a, F186a, F187b, and F187c.

In another aspect of the invention, methods and polypeptides, such as antibody variable domains, are provided comprising one, two or all variant CDRs selected from the group consisting of CDRH1, CDRH2 and CDRH3, wherein said variant CDRH3 comprises an amino acid sequence



wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or is tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;

$X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*, *DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine, phenylalanine, glycine, serine, alanine, leucine, or tryptophan;

$X_3$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is alanine, valine, aspartic acid or glycine;

$X_4$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is methionine;

$X_5$  is aspartic acid, alanine, valine, or glycine; and

$X_6$  is tyrosine or valine;

and wherein the variant CDRH1 or CDRH2 or both comprise at least one variant amino acid in a solvent accessible and highly diverse amino acid position, wherein the variant amino acid is encoded by a nonrandom codon set, wherein at least about 50%, 60%, 70%, 80%, 90%, or all of the amino acids encoded by the nonrandom  
 5 codon set are target amino for that position in known antibodies or antigen binding fragments (for e.g. antibody variable domains).

In some embodiments of any of the methods and polypeptides described herein, the position in H3 is any of positions 95 to 102 of antibody according to Kabat numbering system (e.g. antibody 4D5). For example, position 95 can have a  
 10 variant amino acid encoded by codon set *DVK*, *NVT*, *NNS*, *XYZ*, *NNK* or is tryptophan; position 96 can be encoded by *DVK*, *NVT*, *NNS*, *XYZ*, or is glycine or tryptophan; position 97 can be encoded by *DVK*, *NVT*, *NNS*, *XYZ*, or is tryptophan; position 98 can be encoded by *DVK*, *NVT*, *NNS*, *XYZ*, or is tryptophan; position 99 can be encoded by *DVK*, *NVT*, *NNS*, *XYZ*; position 100 can be encoded by *DVK*,  
 15 *NVT*, *NNS*, *XYZ*, or is tryptophan; position 100a can be encoded by *DVK*, *DSG*, *KSG*, *NVT*, *NNS*, *XYZ*, or can be tyrosine, glycine, serine, alanine, tryptophan, aspartic acid, methionine, phenylalanine, leucine, valine; position 100b can be encoded by *DSG*, *KSG*, *XYZ* or is alanine, tyrosine, glycine, valine, aspartic acid, methionine, or phenylalanine; Position 100c can be encoded by *KSG*, *XYZ*, or is  
 20 methionine, phenylalanine, leucine, alanine, glycine, valine, tyrosine, aspartic acid; position 101 can be encoded by *KSG*, *XYZ* or is aspartic acid, methionine, alanine, valine, glycine, tyrosine, phenylalanine, leucine; and position 102 can be encoded by *KSG* or *XYZ* or is tyrosine, aspartic acid, methionine, alanine, valine, glycine. A polypeptide or plurality of polypeptides comprising a variant CDRH3 region in  
 25 these embodiments can be generated using at least one or more than one of oligonucleotides illustrated in Figure 4 and Figure 43.

In another embodiment, methods and polypeptides, such as antibody variable domains, are provided that comprise at least one or all variant CDRL1, CDRL2 or CDRL3, wherein the variant CDRL1, CDRL2 or CDRL3 or mixtures thereof  
 30 comprise at least one variant amino acid in a solvent accessible and highly diverse amino acid position, wherein the variant amino acid is encoded by a nonrandom codon set, wherein at least about 50%, 60%, 70%, 80%, 90% or all of the amino acids encoded by the nonrandom codon are target amino acids for that position in known antibodies or antigen binding fragments (for e.g. antibody variable domains).

Polypeptides of the invention can be in a variety of forms as long as the target binding function of the polypeptides is retained. In some embodiments, a polypeptide of the invention is a fusion polypeptide (ie. a fusion of two or more sequences from heterologous polypeptides). Polypeptides with diversified CDRs according to the invention can be prepared as fusion polypeptides to at least a portion of a viral coat protein for use in phage display. Viral coat proteins that can be used for display of the polypeptides of the invention comprise protein p III, major coat protein pVIII, Soc (T4 phage), Hoc (T4 phage), gpD (lambda phage), pVI or variants thereof.

10 In some embodiments, in which the polypeptide with diversified CDRs is one or more antibody variable domains, the antibody variable domains can be displayed on the surface of the virus in a variety of formats including ScFv, Fab, ScFv<sub>2</sub>, F(ab')<sub>2</sub> and F(ab)<sub>2</sub>. For display of the polypeptides in bivalent manner, the fusion protein preferably includes a dimerization domain. The dimerization domain can comprise at least one of a dimerization sequence, and/or sequence comprising one or more cysteine residues. The dimerization domain is preferably linked to the C-terminal end of a heavy chain variable or constant domain. The structure of the dimerization domain can be varied depending on whether the antibody variable domain is produced as a fusion protein component with the viral coat protein component (without an amber stop codon after dimerization domain) or whether the antibody variable domain is produced predominantly without viral coat protein component (eg. with an amber stop codon after dimerization domain). When the antibody variable domain is produced predominantly as a fusion protein with viral coat protein component, one or more disulfide bonds and/or a single dimerization sequence provides for bivalent display. For antibody variable domains predominantly produced without being fused to a viral coat protein component (eg. with amber stop), it is preferable to have a dimerization domain comprising both a cysteine residue and a dimerization sequence.

25 In addition, optionally, a fusion polypeptide can comprise a tag that may be useful in purification, detection and screening such as FLAG, poly-his, gD tag, c-myc, fluorescence protein or B-galactosidase. In one embodiment, a fusion polypeptide comprises a light chain variable or constant domain fused to a polypeptide tag.



In another aspect of the invention, a polypeptide such as an antibody variable domain is obtained from a single source or template molecule. The source or template molecule is preferably selected or designed for characteristics such as good yield and stability when produced in prokaryotic or eukaryotic cell culture, and/or to accommodate CDRH3 regions of varying lengths. The sequence of the template molecule can be altered to improve folding and/or display of the variable domain when presented as a fusion protein with a phage coat protein component. For example, a source antibody may comprise the amino acid sequence of the variable domains of humanized antibody 4D5 (light chain variable domain, SEQ ID NO: 1; heavy chain variable domain, SEQ ID NO: 2). For example, in an antibody variable domain of a heavy or light chain, framework region residues can be modified or altered from the source or template molecule to improve folding, yield, display or affinity of the antibody variable domain. In some embodiments, framework residues are selected to be modified from the source or template molecule when the amino acid in the framework position of the source molecule is different from the amino acid or amino acids commonly found at that position in naturally occurring antibodies or in a subgroup consensus sequence. The amino acids at those positions can be changed to the amino acids most commonly found in the naturally occurring antibodies or in a subgroup consensus sequence at that position. In one embodiment, framework residue 71 of the heavy chain may be R, V or A. In another example, framework residue 93 of the heavy chain may be S or A. In yet another example, framework residue 94 may be R, K or T. In yet another example, framework residue 49 in the heavy chain may be alanine or glycine. In the light chain, the amino acid at position 66 may be arginine or glycine.

Methods of the invention are capable of generating a large variety of polypeptides comprising a diverse set of CDR sequences. For example, in one embodiment, the invention provides a polypeptide comprising at least one, two, three, four, five or all of variant CDRs selected from the group consisting of CDR L1, CDR L2, CDR L3, CDR H1, CDR H2 and CDR H3; wherein (i) each of CDRs L1, L2, L3, H1 and H2 has a variant amino acid in at least one (or any number up to all) solvent accessible and highly diverse amino acid position, wherein the variant amino acid is encoded by a non-random codon set, and wherein at least about 50%, 60%, 70%, 80%, 90% or all of the amino acids encoded by the non-random codon set are target amino acids for that position in known antibodies or antigen binding

fragments; and (ii) variant CDR H3 has a variant amino acid in at least one (or any number up to all) amino acid position.

In another embodiment, the invention provides a polypeptide comprising: (a) at least one, two, three, four or all of variant CDRs selected from the group consisting of CDR L1, CDR L2, CDR L3, CDR H1 and CDR H2; wherein each of CDRs L1, L2, L3, H1 and H2 has a variant amino acid in at least one (or any number up to all) solvent accessible and highly diverse amino acid position, wherein the variant amino acid is encoded by a non-random codon set, and wherein at least about 50%, 60%, 70%, 80%, 90% or all of the amino acids encoded by the non-random codon set are target amino acids for that position in known antibodies or antigen binding fragments; and (b) a variant CDR H3 comprising a variant amino acid in at least one (or any number up to all) amino acid position.

In one embodiment, the invention provides a polypeptide comprising at least one, two, three, four, five or all of CDRs selected from the group consisting of CDRL1, CDRL2, CDRL3, CDRH1, CDRH2 and CDRH3, wherein: (a) CDRL1 comprises a variant amino acid in at least one, two, three, four or all of amino acid positions 28, 29, 30, 31 and 32; (b) CDRL2 comprises a variant amino acid in at least one or both of amino acid positions 50 and 53; (c) CDRL3 comprises a variant amino acid in at least one, two, three, four or all of amino acid positions 91, 92, 93, 94 and 96; (d) CDRH1 comprises a variant amino acid in at least one, two, three, four or all of amino acid positions 28, 30, 31, 32 and 33; (e) CDRH2 comprises a variant amino acid in at least one, two, three, four, five or all of amino acid positions 50, 52, 53, 54, 56 and 58; and (f) CDRH3 comprises a variant amino acid in at least one, two, three, four, five, six or all of amino acid positions corresponding to amino acid positions 95, 96, 97, 98, 99, 100, and 100a in antibody 4D5; wherein the amino acid positions correspond to the Kabat numbering system; and wherein each variant amino acid of (a) to (e) is encoded by a non-random codon set, and wherein at least about 50%, 60%, 70%, 80%, 90% or all of the amino acids encoded by the non-random codon set are target amino acids for that amino acid position in known antibodies or antibody fragments. In some embodiments of these polypeptides, at least one variant amino acid of (f) is encoded by codon set *NNK*, *NNS*, *DVK*, *XYZ* or *NVT*. In some embodiments, the polypeptide comprises an antibody heavy and/or light chain variable domain. In some embodiments, CDRH3 amino acid positions 100b, 100c, 101 and 102 are also varied.

In some embodiments, the invention provides a polypeptide comprising antibody light chain and heavy chain variable domains, wherein: (a) CDR L1 comprises a variant amino acid in at least one, two, three, four or all of amino acid positions 28, 29, 30, 31 and 32; (b) CDR L2 comprises a variant amino acid in at least one or both of amino acid positions 50 and 53; (c) CDR L3 comprises a variant amino acid in at least one, two, three, four or all of amino acid positions 91, 92, 93, 94 and 96; (d) CDR H1 comprises a variant amino acid in at least one, two, three, four or all of amino acid positions 28, 30, 31, 32 and 33; (e) CDR H2 comprises a variant amino acid in at least one, two, three, four, five or all of amino acid positions 50, 52, 53, 54, 56 and 58; and (f) CDR H3 comprises a variant amino acid in at least one, two, three, four, five, six or all of amino acid positions corresponding to amino acid positions 95, 96, 97, 98, 99, 100 and 100a in antibody 4D5; wherein the amino acid positions correspond to the Kabat numbering system; and wherein each variant amino acid of (a) to (e) is encoded by a non-random codon set, and wherein at least about 50%, 60%, 70%, 80%, 90% or all of the amino acids encoded by the non-random codon set are target amino acids for that amino acid position in known antibodies or antibody fragments. In some embodiments, the variant amino acid of (f) is encoded by codon set *NNK*, *NNS*, *DVK*, *XYZ* or *NVT* or is tryptophan or glycine or mixtures thereof.

In some embodiments, the invention provides a polypeptide comprising at least one, two, three, four, five or all of CDRs selected from the group consisting of CDR L1, CDR L2, CDR L3, CDR H1, CDR H2 and CDR H3, wherein: (a) CDR L1 comprises a variant amino acid in amino acid positions 28, 29, 30, 31 and 32; (b) CDR L2 comprises a variant amino acid in amino acid positions 50 and 53; (c) CDR L3 comprises a variant amino acid in amino acid positions 91, 92, 93, 94 and 96; (d) CDR H1 comprises a variant amino acid in amino acid positions 28, 30, 31, 32 and 33; (e) CDR H2 comprises a variant amino acid in amino acid positions 50, 52, 53, 54, 56 and 58; and (f) CDR H3 comprises a variant amino acid in amino acid positions corresponding to amino acid positions 95, 96, 97, 98, 99, 100 and 100a in antibody 4D5; wherein the amino acid positions correspond to the Kabat numbering system; and wherein each variant amino acid of (a) to (e) is encoded by a non-random codon set, and wherein at least about 50%, 60%, 70%, 80%, 90% or all of the amino acids encoded by the non-random codon set are target amino acids for that amino acid position in known antibodies or antibody fragments.

In some embodiments, the variant amino acid of (e) is encoded by codon set *NNK*, *NNS*, *DVK*, *XYZ* or *NVT* or tryptophan or glycine or mixtures thereof.

In another embodiment, the invention provides a polypeptide comprising at least one, two, three, four, five or all of CDRs selected from the group consisting of

5 CDRL1, CDRL2, CDRL3, CDRH1, CDRH2 and CDRH3, wherein: (a) CDRL1 comprises a variant amino acid in amino acid positions 28, 29, 30, 31 and 32, wherein: (i) the variant amino acid at position 28 is encoded by codon set *RDT*; (ii) the variant amino acid at position 29 is encoded by codon set *RKT* or *RTT*; (iii) the variant amino acid at position 30 is encoded by codon set *RVW*; (iv) the variant

10 amino acid at position 31 is encoded by codon set *RVW* or *ANW*; (v) the variant amino acid at position 32 is encoded by codon set *DHT* or *THT*; (b) CDRL2 comprises a variant amino acid in amino acid positions 50 and 53, wherein: (i) the variant amino acid at position 50 is encoded by codon set *KBG*; (ii) the variant amino acid at position 53 is encoded by codon set *AVC*; (c) CDRL3 comprises a

15 variant amino acid in amino acid positions 91, 92, 93, 94 and 96, wherein: (i) the variant amino acid at position 91 is encoded by codon set *KMT* or *TMT* or the combination of codon sets *TMT* and *SRT*; (ii) the variant amino acid at position 92 is encoded by codon set *DHT* or *DMC*; (iii) the variant amino acid at position 93 is encoded by codon set *RVT* or *DHT*; (iv) the variant amino acid at position 94 is

20 encoded by codon set *NHT* or *WHT*; (v) the variant amino acid at position 96 is encoded by codon set *YHT*, *HWT*, *HTT* or *TDK* or the combination of codon sets *YKG* and *TWT*; (d) CDRH1 comprises a variant amino acid in amino acid positions 28, 30, 31, 32 and 33, wherein: (i) the variant amino acid at position 28 is encoded by codon set *AVT* or *WCC* or is threonine; (ii) the variant amino acid at position 30

25 is encoded by codon set *RVM* or *AVT*; (iii) the variant amino acid at position 31 is encoded by codon set *RVM*, *RVT* or *RRT*; (iv) the variant amino acid at position 32 is encoded by codon set *WMY*; (v) the variant amino acid at position 33 is encoded by codon set *KVK*, *RNT*, *DMT*, *KMT*, *KGG* or the combination of codon sets *KMT* and *KGG*; (e) CDRH2 comprises a variant amino acid in amino acid positions 50,

30 52, 53, 54, 56 and 58, wherein: (i) the variant amino acid at position 50 is encoded by codon set *KDK* or *DBG* or the combination of codon sets *DGG* and *DHT*; (ii) the variant amino acid at position 52 is encoded by codon set *DHT* or *DMT*; (iii) the variant amino acid at position 53 is encoded by codon set *NMT* or *DMT*; (iv) the variant amino acid at position 54 is encoded by codon set *DMK*, *DMT* or *RRC*; (v)

the variant amino acid at position 56 is encoded by codon set *DMK or DMT*; (vi) the variant amino acid at position 58 is encoded by codon set *DMT or DAC*; and (f) CDRH3 comprises a variant amino acid in amino acid positions 95, 96, 97, 98, 99, 100 and 100a, wherein: the variant amino acid at each of positions 95, 96, 97, 98, 99, 100 and 100a is encoded by codon set *NNK, NNS, XYZ, DVK or NVT* or tryptophan or glycine or mixtures thereof; wherein the amino acid positions correspond to the Kabat numbering system. In some embodiments, the polypeptide comprises an antibody heavy and/or light chain variable domain.

In some embodiments of polypeptides comprise a variant CDRH3, the variant CDRH3 has a variant amino acid in at least one, two, three, four, five, six or all of amino acid positions corresponding to amino acid position 95 to 100a of antibody 4D5 wherein amino acid positions correspond to the Kabat numbering system. In some embodiments, the variant amino acid of variant CDRH3 is an amino acid encoded by codon set *NNK, XYZ, NNS, DVK or NVT* or tryptophan or glycine or mixtures thereof. In some embodiments of polypeptides of the invention, the variant amino acid at position 100a of CDRH3 is encoded by *NNS, NVT, DVK, XYZ*, or is tyrosine, phenylalanine, glycine, serine, alanine, tryptophan, aspartic acid, methionine, or valine. In some embodiments, CDRH3 has a variant amino acid in amino acid positions corresponding to 100b, 100c, 101 and 102 of antibody 4D5.

In various embodiments of polypeptides of the invention, amino acids encoded by a non-random codon set preferably include (generally are) amino acids found at the corresponding position in preferably at least about 50%, 60% or 70% of known antibodies or antigen binding fragments. In some embodiments, said known antibodies or antigen binding fragments are as in "Sequences of Proteins of Immunological Interest" (5th edition) published by the U.S. National Institutes of Health. In some embodiments, said known antibodies or antigen binding fragments are as in the database of Kabat at <http://immuno/bme/nwu/edu>.

In some embodiments of polypeptides of the invention, a nonrandom codon set does not encode cysteine. In some embodiments, a non-random codon set does not include a stop codon.

As described herein, a variant CDR refers to a CDR with a sequence variance as compared to the corresponding CDR of a single reference polypeptide/source antibody. Accordingly, the CDRs of a single polypeptide of the

invention preferably correspond to the set of CDRs of a single reference polypeptide or source antibody.

Polypeptides of the invention can be in a variety of forms as long as the target binding function of the polypeptides are retained. In some embodiments, a polypeptide of the invention is a fusion polypeptide (i.e., a fusion of two or more sequences from heterologous polypeptides). In some embodiments, the fusion polypeptide is fused to at least a portion of a viral coat protein, such as a viral coat protein selected from the group consisting of pIII, pVIII, Soc, Hoc, gpD, pVI, and variants thereof.

10 In some embodiments, a polypeptide of the invention comprises a light chain and a heavy chain antibody variable domain, wherein the light chain variable domain comprises at least 1, 2 or 3 variant CDRs selected from the group consisting of CDR L1, L2 and L3, and the heavy chain variable domain comprises at least 1, 2 or 3 variant CDRs selected from the group consisting of CDR H1, H2 and H3.

15 In some embodiments, a polypeptide of the invention is an ScFv. In some embodiments, it is a Fab fragment. In some embodiments, it is a  $F(ab)_2$  or  $F(ab')_2$ . Accordingly, in some embodiments, a polypeptide of the invention further comprises a dimerization domain. In some embodiments, the dimerization domain is located between an antibody heavy chain or light chain variable domain and at least a portion of a viral coat protein. The dimerization domain can comprise at least one of a dimerization sequence, and/or sequence comprising one or more cysteine residues. The dimerization domain is preferably linked to the C-terminal end of a heavy chain variable or constant domain. The structure of the dimerization domain can be varied depending on whether the antibody variable domain is produced as a fusion protein component with the viral coat protein component (without an amber stop codon after dimerization domain) or whether the antibody variable domain is produced predominantly without viral coat protein component (eg. with an amber stop codon after dimerization domain). When the antibody variable domain is produced predominantly as a fusion protein with viral coat protein component, one or more disulfide bond and/or a single dimerization sequence provides for bivalent display. For antibody variable domains predominantly produced without being fused to a viral coat protein component (eg. with amber stop), it is preferable to have a dimerization domain comprising both a cysteine residue and a dimerization sequence. In some embodiments, heavy chains of the  $F(ab)_2$  dimerize at a

dimerization domain not including a hinge region. The dimerization domain may comprise a leucine zipper sequence (for example, a GCN4 sequence as depicted in SEQ ID NO: 3).

5 In some embodiments, a polypeptide of the invention further comprises a light chain constant domain fused to a light chain variable domain, which in some embodiments comprises at least one, two or three variant CDRs. In some embodiments of polypeptides of the invention, the polypeptide comprises a heavy chain constant domain fused to a heavy chain variable domain, which in some embodiments comprises at least one, two or three variant CDRs.

10 In some embodiments, a polypeptide of the invention comprises an antibody light chain variable domain, wherein the variant CDR is CDR L1 and the amino acid positions that are diversified are those positions that correspond to amino acid positions 28, 29, 30, 31 and 32. In some embodiments, the variant amino acid at position 28 is encoded by codon set *RDT*, the variant amino acid at position 29 is encoded by codon set *RKT* or *RTT*, the variant amino acid at position 30 is encoded by codon set *RVW*, the variant amino acid at position 31 is encoded by codon set *RVW* or *ANW*, and the variant amino acid at position 32 is encoded by codon set *DHT* or *THT*. In one embodiment, the amino acid at position 30 is asparagine or serine.

20 In another embodiment, a polypeptide of the invention comprises an antibody light chain variable domain, wherein the variant CDR is CDR L2, and the amino acid positions that are diversified are those that correspond to amino acid positions 50 and 53. In some embodiments, the variant amino acid at position 50 is encoded by *KBG* codon set, and the variant amino acid at position 53 is encoded by codon set *AVC*.

25 In another embodiment, a polypeptide of the invention comprises an antibody light chain variable domain, wherein the variant CDR is CDR L3, and the amino acid positions that are diversified are selected from those that correspond to amino acid positions 91, 92, 93, 94, or 96. In some embodiments, the variant amino acid at position 91 is encoded by codon set *KMT*, *TMT* or the combination of codon sets *TMT* and *SRT*, the variant amino acid at position 92 is encoded by codon set *DHT* or *DMC*, the variant amino acid at position 93 is encoded by codon set *RVT* or *DHT*, the variant amino acid at position 94 is encoded by codon set *NHT* or *WHT*, and the variant amino acid at position 96 is encoded by codon set *YHT*, *HWT*, *HTT*

or the combination of codon sets *YKG* and *TWT*. In one embodiment, amino acid position 91 is histidine or serine.

In another embodiment, a polypeptide of the invention comprises a heavy chain variable domain, the variant CDR is CDR H1, and the amino acid positions that are diversified are those selected from amino acids positions corresponding to amino acids 28, 30, 31, 32 or 33. In some embodiments, the variant amino acid at position 28 is encoded by codon set *AVT*, *WCC* or is threonine, the variant amino acid at position 30 is encoded by codon set *RVM* or *AVT*, the variant amino acid at position 31 is encoded by codon set *RVM*, *RVT* or *RRT*, the variant amino acid at position 32 is encoded by codon set *WMY*, and the variant amino acid at position 33 is encoded by codon set *KVK*, *RNT*, *DMT*, *KMT* or the combination of codon sets *KMT* and *KGG*.

In another embodiment, a polypeptide of the invention comprises a heavy chain variable domain, the variant CDR is CDR H2, and the amino acid positions that are diversified are those selected from amino acid positions corresponding to amino acids 50, 52, 53, 54, 56 or 58. In some embodiments, the variant amino acid at position 50 is encoded by codon set *KDK*, *DBG* or the combination of codon sets *DGG* and *DHT*, the variant amino acid at position 52 is encoded by codon set *DHT* or *DMT*, the variant amino acid at position 53 is encoded by codon set *NMT* or *DMT*, the variant amino acid at position 54 is encoded by codon set *DMK*, *DMT* or *RRC*, the variant amino acid at position 56 is encoded by codon set *DMK* or *DMT*, and the variant amino acid at position 58 is encoded by codon set *DMT* or *DAC*.

In another embodiment, a polypeptide of the invention comprises a heavy chain variable domain, and the variant CDR is CDR H3 comprising a variant amino acid in at least one, two, three, four, five, six or all of amino acid positions 95 to 100a, wherein the variant amino acids is encoded by codon set *NNK*, *NNS*, *XYZ*, *DVK* or *NVT* or tryptophan or glycine or mixtures thereof.

In some instances, it may be preferable to mutate a framework residue such that it is variant with respect to a reference polypeptide or source antibody. For example, framework residue 71 of the heavy chain may be amino acid R, V or A. In another example, framework residue 93 of the heavy chain may be amino acid S or A. In yet another example, framework residue 94 of the heavy chain may be amino acid R, K or T or encoded by *MRT*. In yet another example, framework residue 49 of the heavy chain may be amino acid A or G. Framework residues in the light chain



may also be mutated. For example, framework residue 66 in the light chain may be amino acid R or G.

As described herein, a variant CDR refers to a CDR with a sequence variance as compared to the corresponding CDR of a single reference polypeptide/source antibody. Accordingly, the CDRs of a single polypeptide of the invention preferably correspond to the set of CDRs of a single reference polypeptide or source antibody. Polypeptides of the invention may comprise any one or combinations of variant CDRs. For example, a polypeptide of the invention may comprise a variant CDRH1 and CDRH2. A polypeptide of the invention may comprise a variant CDRH1, variant CDRH2 and a variant CDRH3. In another example, a polypeptide of the invention may comprise a variant CDRH1, H2, H3 and L3. In another example, a polypeptide of the invention comprises a variant CDRL1, L2 and L3. Any polypeptide of the invention may further comprise a variant CDRL3. Any polypeptide of the invention may further comprise a variant CDRH3.

Polypeptides of the invention may be in a complex with one another. For example, the invention provides a polypeptide complex comprising two polypeptides, wherein each polypeptide is a polypeptide of the invention, and wherein one of said polypeptides comprises at least one, two or all of variant CDRs H1, H2 and H3, and the other polypeptide comprises a variant CDR L3. A polypeptide complex may comprise a first and a second polypeptide (wherein the first and second polypeptides are polypeptides of the invention), wherein the first polypeptide comprises at least one, two or three variant light chain CDRs, and the second polypeptide comprises at least one, two or three variant heavy chain CDRs. The invention also provides complexes of polypeptides that comprise the same variant CDR sequences. Complexing can be mediated by any suitable technique, including by dimerization/multimerization at a dimerization/multimerization domain such as those described herein or covalent interactions (such as through a disulfide linkage) (which in some contexts is part of a dimerization domain, for e.g. a dimerization domain may contain a leucine zipper sequence and a cysteine).

In another aspect, the invention provides compositions comprising polypeptides and/or polynucleotides of the invention. For example, the invention provides a composition comprising a plurality of any of the polypeptides of the invention described herein. Said plurality may comprise polypeptides encoded by a

plurality of polynucleotides generated using a set of oligonucleotides comprising degeneracy in the sequence encoding a variant amino acid, wherein said degeneracy is that of the multiple codon sequences of the nonrandom codon set encoding the variant amino acid.

5           In one aspect, the invention provides a polynucleotide encoding a polypeptide of the invention as described herein. A polynucleotide of the invention may be a replicable expression vector comprising a sequence encoding a polypeptide of the invention.

10           In another aspect, the invention provides a library comprising a plurality of vectors of the invention, wherein the plurality of vectors encode a plurality of polypeptides.

The invention also provides a host cell comprising any of the polynucleotides and/or vectors of the invention described herein.

15           In another aspect, the invention provides a virus or viral particle (such as phage or phagemid particles) displaying a polypeptide of the invention on its surface. The invention also provides a library comprising a plurality of the viruses or viral particles of the invention, each virus or virus particle displaying a polypeptide of the invention. A library of the invention may comprise any number of distinct polypeptides (sequences), preferably at least about  $1 \times 10^8$ , preferably at  
20           least about  $1 \times 10^9$ , preferably at least about  $1 \times 10^{10}$  distinct sequences.

The invention also provides libraries containing a plurality of polypeptides, wherein each type of polypeptide is a polypeptide of the invention as described herein.

25           In another aspect of the invention provides methods for selecting for high affinity binders to specific target antigens such as growth hormone, bovine growth hormone, insulin like growth factors, human growth hormone including n-methionyl human growth hormone, parathyroid hormone, thyroxine, insulin, proinsulin, amylin, relaxin, prolaxin, glycoprotein hormones such as follicle stimulating hormone (FSH), leutinizing hormone (LH), hemapoietic growth factor, fibroblast  
30           growth factor, prolactin, placental lactogen, tumor necrosis factors, mullerian inhibiting substance, mouse gonadotropin -associated polypeptide, inhibin, activin, vascular endothelial growth factors, integrin, nerve growth factors such as NGF-beta, insulin-like growth factor- I and II, erythropoietin, osteoinductive factors,

interferons, colony stimulating factors, interleukins, bone morphogenetic proteins, LIF, SCF, FLT-3 ligand and kit-ligand.

The methods of the invention provide for libraries of polypeptides (eg. antibody variable domains) with one or more diversified CDR regions. These libraries are sorted (selected) and/or screened to identify high affinity binders to a target antigen. In one aspect, polypeptide binders from the library are selected for binding to target antigens, and for affinity. The polypeptide binders selected using one or more of these selection strategies, then, may be screened for affinity and/or for specificity (binding only to target antigen and not to non-target antigens).

A method comprises generating a plurality of polypeptides with one or more diversified CDR regions, sorting the plurality of polypeptides for binders to a target antigen by contacting the plurality of polypeptides with a target antigen under conditions suitable for binding; separating the binders to the target antigen from those that do not bind; isolating the binders; and identifying the high affinity binders. The affinity of the binders that bind to the target antigen can be determined using competition ELISA such as described herein. Optionally, the polypeptides can be fused to a polypeptide tag such as gD, poly his or FLAG which can be used to sort binders in combination with sorting for the target antigen.

Another embodiment provides a method of selecting for an antibody variable domain that binds to a target antigen from a library of antibody variable domain comprising: a) generating a library of replicable expression vectors comprising a plurality of polypeptides of any of claims 1 to 9 and 17 to 44; b) isolating polypeptide binders to a target antigen from the library by contacting the library with an immobilized target antigen under conditions suitable for binding; c) separating the polypeptide binders in the library from the nonbinders and eluting the binders from the target antigen; d) amplifying the replicable expression vectors having the polypeptide binders; and e) optionally, repeating steps a-d at least twice.

The method may further comprise: f) incubating the amplified replicable expression vectors comprising polypeptide binders with a concentration of labelled target antigen in the range of 0.1 nM to 1000 nM under conditions suitable for binding to form a mixture; g) contacting the mixture with an immobilized agent that binds to the label on the target antigen; h) separating the polypeptide binders bound to labelled target antigen and eluting the polypeptide binders from the labelled target antigen; i) amplifying replicable expression vectors comprising the polypeptide

binders; and j) optionally, repeating steps f) to i) at least twice, using a lower concentration of labelled target antigen each time. Optionally, the method may comprise adding an excess of unlabelled target antigen to the mixture and incubating for a period of time sufficient to elute low affinity binders from the labelled target antigen.

Another embodiment provides a method of isolating or selecting for high affinity binders to a target antigen from a library of replicable expression vectors comprising: a) generating a library of replicable expression vectors comprising a plurality of polypeptides of any of claims 1-9 and 17-44; b) contacting the library with a target antigen in a concentration of at least about 0.1 nM to 1000 nM to isolate polypeptide binders to the target antigen; c) separating the polypeptide binders from the target antigen and amplifying the replicable expression vector comprising the polypeptide binders; d) optionally, repeating steps a-c at least twice, each time with a lower concentration of target antigen to isolate polypeptide binders that bind to lowest concentration of target antigen; e) selecting the polypeptide binder that binds to the lowest concentration of the target antigen for high affinity by incubating the polypeptide binders with several different dilutions of the target antigen and determining the IC<sub>50</sub> of the polypeptide binder; and f) identifying a polypeptide binder that has an affinity for the target antigen of about 0.1 nM to 200 nM.

Another embodiment provides an assay for selecting polypeptide binders from a library of replicable expression vectors comprising a plurality of polypeptides of any of claims 1 to 9 and 17 to 44 comprising: a) contacting the library with a concentration of labelled target antigen in a concentration range of 0.1 nM to 1000 nM, under conditions suitable for binding to form a complex of a polypeptide binders and the labelled target antigen; b) isolating the complexes and separating the polypeptide binders from the labelled target antigen; c) amplifying the replicable expression vector comprising the polypeptide binders; d) optionally, repeating steps a-c at least twice, each time using a lower concentration of target antigen. Optionally, the method may further comprise adding an excess of unlabelled target antigen to the complex of the polypeptide binder and target antigen. In a preferred embodiment, the steps of the method are repeated twice and the concentrations of target in the first round of selection is about 100 nM to 250 nM, and in the second

round of selection is about 25 nM to 100 nM, and in the third round of selection is about 0.1 nM to 25 nM.

The invention also includes a method of screening a library of replicable expression vectors comprising a plurality of polypeptides of any of claims 1 to 9 and 17-44 comprising: a) incubating first a sample of the library with a concentration of a target antigen under conditions suitable for binding of the polypeptides to the target antigen; b) incubating a second sample of the library without a target antigen; c) contacting each of the first and second sample with immobilized target antigen under conditions suitable for binding of the polypeptide to the immobilized target antigen; d) detecting the amount of the bound polypeptides to immobilized target antigen for each sample; e) determining the affinity of the polypeptide for the target antigen by calculating the ratio of the amounts of bound polypeptide from the first sample over the amount of bound polypeptide from the second sample.

The libraries generated as described herein may also be screened for binding to a specific target and for lack of binding to nontarget antigens. In one aspect, another embodiment provides a method of screening for an antibody variable domain that binds to a specific target antigen from a library of antibody variable domain comprising: a) generating a library of replicable expression vectors comprising a plurality of polypeptides of any of claims 1 to 9 and 17 to 44; b) contacting the library with a target antigen and at least one nontarget antigen under conditions suitable for binding; c) separating the polypeptide binders in the library from the nonbinders; d) identifying the binders that bind to the target antigen and do not bind to the nontarget antigen; e) eluting the binders from the target antigen; and f) amplifying the replicable expression vectors comprising the polypeptide binder that bind to a specific antigen.

Combinations of any of the sorting/ selection methods described above may be combined with the screening methods. For example, in one embodiment, polypeptide binders are first selected for binding to immobilized target antigen. Polypeptide binders that bind to the immobilized target antigen can then be amplified and screened for binding to the target antigen and for lack of binding to nontarget antigens. Polypeptide binders that bind specifically to the target antigen are amplified. These polypeptide binders can then be selected for higher affinity by contact with a concentration of a labelled target antigen to form a complex, wherein the concentration range of labelled target antigen is from about 0.1 nM to about

1000 nM, the complexes are isolated by contact with an agent that binds to the label on the target antigen. The polypeptide binders are then eluted from the labeled target antigen and optionally, the rounds of selection are repeated, each time a lower concentration of labelled target antigen is used. The high affinity polypeptide binders isolated using this selection method can then be screened for high affinity using for example, the solution phase ELISA assay as described in Example 8 or the spot competition ELISA assay as described in Example 9.

### BRIEF DESCRIPTION OF THE FIGURES

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Figure 1 shows the frequency of amino acids (identified by single letter code) in human antibody light chain CDR sequences from the Kabat database. The frequency of each amino acid at a particular amino acid position is shown starting with the most frequent amino acid at that position at the left and continuing on to the right to the least frequent amino acid. The number below the amino acid represents the number of naturally occurring sequences in the Kabat database that have that amino acid in that position.

Figure 2 shows the frequency of amino acids (identified by single letter code) in human antibody heavy chain CDR sequences from the Kabat database. The frequency of each amino acid at a particular amino acid position is shown starting with the most frequent amino acid at that position at the left and continuing on to the right to the least frequent amino acid. The number below the amino acid represents the number of naturally occurring sequences in the Kabat database that have that amino acid in that position. Framework amino acid positions 71, 93 and 94 are also shown.

Figure 3 shows illustrative embodiments of suitable codon set design for amino acid positions in CDRL1, CDRL2, CDRL3, CDRH1 and CDRH2. The codon sets are identified by three capital letters in italics and are bracketed by < and >, e.g. <RDT>. The amino acids encoded by that codon set are indicated by single letter code under the column labelled Diversity<DNA codon>. The column labelled Natural Diversity shows the most commonly occurring amino acids at those positions in the naturally occurring antibody variable domains in the Kabat database. The %

good is the % of amino acids that are encoded by the codon set that are target amino acids for that position. The % covering is the % of natural occurring antibodies in the Kabat database that have the amino acids encoded by the codon set at that position.

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Figures 4A & B & C show illustrative embodiments of designed diversity in CDRH3. The different oligonucleotides encode for diversity at amino acid positions in CDRH3 as well as diversity in sequence length. The oligonucleotides are identified as F59, F63, and F64 etc in the left hand column. The amino acid sequence at each amino acid position for CDRH3 for each oligonucleotide is shown. The CDRH3 sequence in the source antibody 4D5 is shown across the top: S<sub>93</sub>, R<sub>94</sub>, W<sub>95</sub>, G<sub>96</sub>, G<sub>97</sub>, D<sub>98</sub>, G<sub>99</sub>, F<sub>100</sub>, Y<sub>100a</sub>, A<sub>100b</sub>, M<sub>100c</sub>, D<sub>101</sub>, and Y<sub>102</sub>. Amino acid positions 93 and 94 are considered framework positions. In some embodiments, certain positions may have a fixed amino acid shown in single letter code, e.g. position 93 is S(serine); amino acid position 94 may be R/K/T ( arginine/lysine /threonine); amino acid position 100a may be G/S/A/W(glycine/serine/alanine/tryptophan). Other amino acid positions are diversified using codon sets identified by three capital letters in italics, e.g. *DVK*, *NVT*, *DSG*, *KSG*. The length of the CDRH3 is indicated at the right column. The lengths of the CDRH3 regions varied from 7 to 15. The diversity of the library generated with the strategy shown for each oligonucleotide is also shown on the right. A single oligonucleotide may be used or oligonucleotides may be pooled to generate a library.

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Figure 5 shows an illustrative embodiment of designed diversity for CDR's L1 and L2 and L3. The codon sets for each position is shown. The amino acids (in single letter code) encoded by the codon set at each position are shown below in a column. The diversity generated with this design results in a library with  $2.9 \times 10^9$  sequences.

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Figure 6 shows an illustrative embodiment of designed diversity using nonrandom codon sets for amino acid positions in CDRL1, L2 and L3. The amino acids (in single letter code) encoded by the codon set at each position are shown.

below in a column. The diversity generated with this design results in  $6.1 \times 10^8$  sequences.

Figure 7 shows an illustrative embodiment of designed diversity using nonrandom codon sets at amino acid positions in CDRL3. The amino acids (in single letter code) encoded by the codon set at each position are shown below in a column.

Figure 8 shows an illustrative embodiment of designed diversity using nonrandom codon sets for CDRs L1, L2 and L3. At some positions, the codon set may encode an increased proportion of one or more amino acids. For example, at position 93 in CDRL3, codon set *RTM* encodes an increased proportion of alanine (A2), glycine (G2) and threonine (T2). The amino acids (in single letter code) encoded by the codon set at each position are shown below in a column.

Figure 9 shows an illustrative embodiment of designed diversity using nonrandom codon sets at amino acid positions in CDRH1, H2 and H3. The amino acids (in single letter code) encoded by the codon set at each position are shown below in a column.

Figure 10 shows an illustrative embodiment of designed diversity using nonrandom codon set at amino acid positions in CDRs H1, H2 and H3. The amino acids (in single letter code) encoded by the codon set at each position are shown below in a column.

Figure 11 shows an illustrative embodiment of designed diversity using nonrandom codon sets at amino acid positions in CDRs in H1, H2, H3 and L3. The amino acids (in single letter code) encoded by the codon set at each position are shown below in a column.

Figure 12 shows an illustrative embodiment of designed diversity using nonrandom codon sets at amino acid positions in CDRs in H1, H2, H3 and L3. The amino acids (in single letter code) encoded by the codon set at each position are shown below in a column.



Figure 13 shows an illustrative embodiment of designed diversity using nonrandom codon sets at amino acid positions in CDRs H1, H2, H3 and L3. The amino acids (in single letter code) encoded by the codon set at each position are shown below in a column.

Figures 14 A & B shows nucleotide sequence of Ptac promoter driver cassette for display of ScFv (SEQ ID NO: 23). Sequences encoding *malE* secretion signal, humanized antibody 4D5 light chain variable domain, linker, gD tag, humanized 4D5 heavy chain variable domain, and C-terminal domain of p3 (cP3) are indicated.

Figures 15 A & B shows the DNA sequence of the Ptac promoter driver cassette for display ScFv-zip (SEQ ID NO: 24). Sequences encoding *malE* secretion signal, humanized 4D5 light chain variable domain, linker, gD tag, humanized 4D5 heavy chain variable domain, zipper sequence, and C-terminal domain p3 (cP3) are indicated.

Figures 16 A & B shows DNA sequence of the Ptac promoter driven cassette for display of Fab (SEQ ID NO: 25). Two open reading frames are indicated. The first open reading frame encodes a *malE* secretion signal, humanized 4D5 light chain variable and constant domain. The second open reading frame encodes stII secretion signal, humanized heavy chain variable domain, humanized 4D5 heavy chain first constant region (CH1) and C-terminal domain of p3.

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Figures 17 A & B shows the DNA sequence of Ptac promoter driven cassette for display of Fab-zip (SEQ ID NO: 26). Two open reading frames are indicated. The first open reading frame encodes a *malE* secretion signal, humanized 4D5 light chain variable and constant domain. The second open reading frame encodes a stII secretion signal, humanized 4D5 heavy chain variable domain, humanized 4D5 heavy chain first constant domain (CH1), zipper sequence, and C-terminal of p3 (cP3).

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Figure 18 shows a schematic representation of display of different constructs including F(ab) and F(ab')<sub>2</sub>. (A) shows a Fab with a light chain, and a heavy chain variable and CH1 domain fused to at least a portion of a viral coat protein; (B) shows a F(ab')<sub>2</sub> with two light chains, and one heavy chain with a dimerization domain(zip) fused to at least a portion of the viral coat protein; an amber stop codon is present after the dimerization domain and (C) shows a F(ab')<sub>2</sub> with two light chains, and both heavy chain variable and CH1 domains, each with a dimerization domain, and each fused to at least a portion of the viral coat protein

Figure 19 shows a graph of the % bound of Fab phage constructs in the presence of increasing amounts of HER-2ecd (target antigen). The constructs are Fab phage (-○-) or zipped F(ab')<sub>2</sub> phage (-●-). The F(ab) or zipped F(ab')<sub>2</sub> phage, each was incubated with increasing concentrations of Her-2ECD (0.001 to 1000 nM) in solution for 5 hours at 37°C. The unbound phage was captured with plates coated with Her-2ECD and measured with HRP-anti-M13 conjugate.

Figure 20 shows the differences in off rate between Fab (-○-) or zipped F(ab')<sub>2</sub> (-●-) phage. Serial dilutions of Her-2ECD (0.01 nM to 1000 nM) were added to Fab or zipped F(ab')<sub>2</sub> phage bound to Her-2ECD coated wells. The phage remaining bound to the plate was quantified using HRP-anti-M13 conjugate. The relative proportion of remaining phage bound as a percentage was calculated by dividing OD at a particular Her-2ECD concentration with OD in absence of Her-2ECD.

Figure 21 shows the differences in the amount of phage F(ab) phage (-○-) or zipped F(ab')<sub>2</sub> (-●-) that is required to give detectable binding on a ligand coated support by standard phage ELISA. Differing concentrations of phage were diluted and the binding signal on Her-2ECD coated plates was detected with HRP-anti-M13 measured at an O.D. of 450nm.

Figure 22 shows the ability to detect a low affinity binder using divalent display. A humanized 4D5 mutant was prepared with arginine 50 changed to alanine (R50A) in both F(ab) phage (-○-) or zipped F(ab')<sub>2</sub> (-●-) format. The phage

was diluted and the binding on Her-2ECD coated plates was detected with HRP anti-M13.

Figure 23 shows the comparison of the frequency of amino acid types in CDRH3 regions in naturally occurring antibodies (solid bar) and in antibody variable domains with diversity generated with *NNK* codon sets (stippled bar). Amino acids are grouped as follows: phenylalanine (F), tryptophan (W) and tyrosine (Y) are aromatic amino acids; isoleucine (I), leucine (L), valine (V), alanine (A), and methionine (M) are aliphatic, lysine (K), arginine (R), and histidine (H) are basic; aspartic acid (D) and glutamic acid (E) are acidic; serine (S), threonine (T), asparagine (N), and glutamine (Q) are polar; and proline (P), glycine (G), and cysteine (C) are conformational.

Figure 24 shows an illustrative embodiment of designed diversity using nonrandom codon sets for amino acid positions in CDRs H1, H2 and H3. The amino acids (in single letter code) encoded by the codon set at that position are shown below in a column.

Figure 25 shows the results from sorting ScFv libraries for binding to target antigens Her-2, IGF-1 and mVEGF. The ScFv-1 library was generated with a vector having a zipper sequence and with diversity in CDRH1, H2 and H3. The ScFv-2 was generated with a vector having a zipper sequence and with diversity in H1, H2, H3 and L3. The ScFv-3 was generated with a vector with a zipper sequence and with diversity in H3 and L3. The ScFv-4 has no zipper region and the CDR diversity was generated in CDR H1, H2 and H3. The ScFv-5 was generated with no zipper sequence and with CDR diversity in CDR's H1, H2, H3 and L3. The results for each library after three rounds of sorting are shown as a % of clones binding to a target antigen.

Figure 26 shows the results of specific binders isolated from ScFv-1, ScFv-2 and ScFv-3 libraries. Phage clones from 3 rounds of selection against IGF-1 or mVEGF were analyzed for specific binding by ELISA assays using both IGF1 and mVEGF. Clones that bound to the target for which they were selected and not to the other antigen were identified as specific. The percentage of clones from each

selection that bound targets (Total) and the percentage of clones that bound only the target against which they were selected (specific) are shown.

Figure 27 shows the total number of sequences and of those sequences the number of unique sequences of anti-VEGF or anti-IGF antibody variable domains identified from each library of scFv-1 and scFv-4 after two or three rounds of sorting.

Figure 28 shows an example of CDRH3 codon/amino acid usage distribution in one set of binders. "X" denotes codon set usage as shown for each oligonucleotides in Figure 4. The percentage of the CDR-H3 design of each oligonucleotides in the sequences of binders isolated from the library are shown.

Figure 29 shows H3 sequences and affinities of some anti-IGF1 and anti-VEGF binders from a F(ab')<sub>2</sub> L3/H3 library. Underlined residues represent residues that were fixed in the source library of the clones.

Figure 30 shows the identity of the epitope bound by some of the clones. Murine VEGF was coated on plate and phage clones competitively inhibited in the present of KDR-7igg were identified. Clones V1 (-●-), V2(-○-), V4 (-◆ -), V5 (-▲ -), V6 (-+ -), V7 (- Δ -), V8 (- -), V9 (-■-), V10 (-▼-) were tested.

Figure 31 shows the identity of the epitope bound by some of the clones. Murine VEGF was coated on a plate and phage clones competitively inhibited in the present of Flt1-D2 were identified. Clones V1 (-●-), V2(-○-), V4 (-◆ -), V5 (-▲ -), V6 (-+ -), V7 (- Δ -), V8 (- -), V9 (-■-), V10 (-▼-) were tested.

Figure 32 shows the Fab polypeptide phage CDRH3 amino acid sequences, affinities, epitope specificity and production of Fab in cell culture for clones V1, V2, V3, and V8.

Figure 33 shows the heavy chain variable domain CDR amino acid sequences and affinities of binders to mVEGF and human Fc receptor from a F(ab)

or F(ab')<sub>2</sub> library. The amino acid sequence of heavy chain framework positions 49, 71, 93 and 94 are also shown.

Figures 34 A - D are a schematic illustration of phagemid constructs. Figure 34A shows a bicistronic vector allowing expression of separate transcripts for display of Fab. A suitable promoter, such as Ptac or PhoA promoter drives expression of the bicistronic message. The first cistron encodes a *malE* or heat stable enterotoxin II (stII) secretion signal connected to a sequence encoding a light chain variable and constant domain and a gD tag. The second cistron encodes a secretion signal sequence, a heavy chain variable domain and constant domain 1 (CH1) and at least a portion of a viral coat protein. Figure 34B shows a bicistronic message for display of F(ab')<sub>2</sub>. A suitable promoter drives expression of the first and second cistron. The first cistron encodes a secretion signal sequence (*malE* or stII), a light chain variable and constant domain and a gD tag. The second cistron encodes a secretion signal, a sequence encoding heavy chain variable domain and constant domain 1 (CH1) and dimerization domain and at least a portion of the viral coat protein. Figure 34C is a monocistronic vector for display of ScFv. A suitable promoter drives expression of V<sub>L</sub> and V<sub>H</sub> domains linked by a peptide linker. The cistronic sequence is connected at the 5' end to a secretion signal sequence and at 3' end to at least a portion of a viral coat protein (pIII). Figure 34D shows a vector for display of ScFv<sub>2</sub>. The vector is similar to Figure 34C, but comprises a dimerization domain between V<sub>H</sub> and the coat protein.

Figure 35 shows the amino acid sequences for heavy chain variable CDR sequences and affinities of anti-VEGF binders from a ScFv and ScFv<sub>2</sub> library.

Figure 36 shows a 3-D modeled structure of humanized 4D5 showing CDR residues that form contiguous patches. Contiguous patches are formed by amino acid residues 28, 29,30,31 and 32 in CDRL1; amino acids residues 50 and 53 of CDRL2; amino acid residues 91,92, 93, 94 and 96 of CDRL3; amino acid residues 28, 30, 31, 32,33 in CDRH1; and amino acid residues 50,52,53,54,56, and 58 in CDRH2.

Figure 37 A-F shows the DNA (SEQ ID NO:28) and amino acid sequence of pV3050-2b vector. The sequence shows stII secretion signal sequence, light

chain variable and constant domain of 4D5, and a gD tag, another stII secretion signal sequence heavy chain variable domain sequence of 4D5, CHI heavy chain constant domain, and C-terminal domain of p3.

5           Figure 38 A-F shows the DNA (SEQ ID NO: 29) and amino acid sequence of vector pV-0350-4. The pV0350-2b vector was modified by inserting a dimerization domain between heavy chain constant CH1 domain and p3 sequences.

10           Figure 39 shows a schematic illustration of constructs with different dimerization domains: Fab'-zip with hinge region and leucine zipper, cysteine-free hinge plus zipper (Fab'(C→A)-zip), zipper alone (Fab-zip), one cysteine plus zipper (Fab-C-zip) or just one cysteine (Fab-C) by itself between Fab and cP3.

15           Figure 40 shows the avidity index of variants with variations in dimerization domains in the presence of amber stop codons (cross hatch) or in the absence of an amber stop codon (solid bar) after the dimerization domain. Assays were performed as in Fig.20 in triplicate and the avidity index is the percentage of phage remained bound after 500 nM ErbB2-ECD incubation relative to phage bound in a sample incubated without ErbB2-ECD. The significance of the differences were analysed with t-test. One asterisk (\*) represents significant difference compared to Fab phage of equal amber stop status (p-values <0.001, except that Fab' (C→A)-zip and Fab-zip (-amber) have p value as 0.001-0.003). Two asterisks (\*\*) represent significant difference comparing between with and without the amber stop codon (p<0.01). Three asterisks (\*\*\*) indicate significant difference comparing amber-less constructs of Fab' (C→A)-zip and Fab-zip against Fab'-zip phage (p = 0.003-0.007).

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30           Figure 41 shows western blot of constructs with different dimerization domains under reducing conditions (Panels C and D) and non-reducing conditions (Panels A and B). Phage samples are labelled at the bottom of each lane and MW markers are labelled at the left. All constructs contained gD-tag fused to the C terminus of the light chain.

Western blot samples were run under non-reducing (-DTT; Panels A and B) or reducing (+DTT; Panels C and D) conditions, and proteins were detected with an anti-gD-tag antibody (Panels A and C) or anti-P3 antibody (Panels B and D). Phage

infected XL-1Blue cells were grown at 30 °C overnight in 2YT medium and phage were purified by precipitation twice with PEG/NaCl and resuspended in 1 mL of 10 mM TRIS, 1.0 mM EDTA, pH 8.0. Phage samples ( $3 \times 10^{11}$ ,  $1 \text{OD}_{268} = 1.3 \times 10^{13}$ ) were incubated at 95 °C for 5 min in SDS-PAGE sample buffer (2% SDS, 20mM Tris pH 6.8, 10% glycerol) with or without 2mM DTT. The denatured samples were run on a 4-20% Tris-Glycine gel and then electro-transferred to a PVDF filter. The PVDF filter was blocked with 2% milk and 0.1% Tween20 in Tris, pH 7.5, 0.15M NaCl (blocking buffer) for 2 h and then incubated with 2nM of anti-gD-tag (left) or anti-P3 (right) antibody in blocking buffer for 1 h. The filter was washed with PBS, 0.05% Tween20, incubated with horse radish peroxidase/rabbit anti-mouse Fab conjugate for 30 min and visualized with ECL<sup>TM</sup> western blotting detection reagent (Amersham Life Sciences).

Figure 42 shows a comparison of frequency of amino acids in CDRH3 in naturally occurring antibodies (solid bar ); amino acids encoded by codon set (A) *DVK* (cross hatch bar); (B) *XYZ* ( cross hatch bar); and (C) *NNK* ( cross hatch bar). Amino acids are grouped as follows: phenylalanine (F), tryptophan (W) and tyrosine (Y) are aromatic amino acids; isoleucine (I) , leucine (L), valine (V), alanine(A), and methionine (M) are aliphatic, lysine (K), arginine(R), and histidine (H) are basic; aspartic acid (D) and glutamic acid (E) are acidic; serine (S), threonine(T), asparagine (N), and glutamine (Q) are polar; and proline (P), glycine (G), and cysteine (C) are conformational.

Figure 43 shows embodiments of oligonucleotides encoding diversity in sequence and in length of CDRH3. The oligonucleotides are identified as F171, F185, F185a etc. in the left hand column. The amino acid sequence at each amino acid position for CDRH3 using each oligonucleotide is shown. The CDRH3 sequence in the source antibody 4D5 is : S<sub>93</sub>, R<sub>94</sub>, W<sub>95</sub> , G<sub>96</sub>, G<sub>97</sub>, D<sub>98</sub>, G<sub>99</sub> , F<sub>100</sub> , Y<sub>100a</sub> , A<sub>100b</sub> , M<sub>100c</sub> , D<sub>101</sub> , and Y<sub>102</sub>. Amino acid positions 93 and 94 are considered framework positions. In some embodiments, certain positions may have a fixed amino acid shown in single letter code, e.g. position 93 is A(alanine); amino acid position 94 may be R/K (arginine /lysine); amino acid position 100a may be A/G/V/D (alanine/glycine/ valine/aspartic acid). Other amino acid positions are

diversified using codon sets identified the three capital letters in italics, e.g. *NNK*, *XYZ*, *NNS*, *KSG*. The length of the CDRH3 is indicated on the right column.

Figure 44 shows schematic illustration of sorting strategies to select for high affinity anti-VEGF antibody variable domains from libraries using solid support bound target (---) or solution phase target binding as described in Example 9.

Figure 45 shows a schematic depiction of two kinds of sorting strategies for selecting high affinity antibody variable domains. The sorting or selection includes sorting against target bound to solid substrate and/or sorting against solution phase target antigens as described in Example 9.

Figure 46 shows the correlation of affinity determination based on IC50 from a competition ELISA as described in Example 8 with KD of the same clone.

Figure 47 shows a schematic representation of single spot competition ELISA for binders. The graph shows the data from screening about 40 clones. The % inhibition of binding was calculated by calculating the ratio of OD of samples plus target over samples minus target. The lower the %, the higher the potential affinity. The results show, that of the 40 clones, there was a range of affinities. About 10% of the clones were of very high affinity.

SEQ ID NO:	Name	Sequence	Page
1	4D5 light chain variable domain	Asp Ile Gln Met Thr Gln Ser Pro Ser Ser Leu Ser Ala Ser Val Gly Asp Arg Val Thr Ile Thr Cys Arg Ala Ser Gln Asp Val Asn Thr Ala Val Ala Trp Tyr Gln Gln Lys Pro Gly Lys Ala Pro Lys Leu Leu Ile Tyr Ser Ala Ser Phe Leu Glu Ser Gly Val Pro Ser Arg Phe Ser Gly Ser Arg Ser Gly Thr Asp - #Phe Thr Leu Thr Ile Ser Ser Leu Gln Pro Glu Asp Phe Ala Thr Tyr Tyr Cys Gln Gln His Tyr Thr Thr Pro Pro Thr Phe Gly Gln Gly Thr Lys Val Glu Ile Lys Arg Thr	12



2	4D5 heavy chain variable domain	Glu Val Gln Leu Val Glu Ser Gly Gly Gly Leu Val Gln Pro Gly Gly Ser Leu Arg Leu Ser Cys Ala Ala Ser Gly Phe Asn Ile Lys Asp Thr Tyr Ile His Trp Val Arg Gln Ala Pro Gly Lys Gly Leu Glu Trp Val Ala Arg Ile Tyr Pro Thr Asn Gly Tyr Thr Arg Tyr Ala Asp Ser Val Lys Gly Arg Phe Thr Ile Ser Ala Asp Thr Ser Lys Asn Thr Ala Tyr Leu Gln Met Asn Ser Leu Arg Ala Glu Asp Thr Ala Val Tyr Tyr Cys Ser Arg Trp Gly Gly Asp Gly Phe Tyr Ala Met Asp Val Trp Gly Gln Gly Thr Leu Val Thr Val Ser Ser	12
3	GNC4 leucine zipper	GRMKQLEDKVEELLSKNYHLENE VARLKKLVGERG	18
4	C-terminal of CDRH3	YAMDY	7
5	heavy chain CDR3	SRNAWAF	89
6	heavy chain CDR3	SRNLSENSYAM	89
7	heavy chain CDR3	SRAGWAGWYAM	89
8	heavy chain CDR3	SRAAKAGWYAM	89
9	heavy chain CDR3	SRSDGRDSAYAM	89
10	F63	SRXXXXXXXXXAMDY	Figure 4
11	F65	SRXXXXXXXXXYAMDY	Figure 4
12	F64	SRXXXXXXXXXYAMDY	Figure 4
13	F66	SRXXXXXXXXXYAMDY	Figure 4
14	oligonucleotide F151	gca gct tct ggc ttc acc att ant nnt nnn nnt ata cac tgg gtg cgt cag	92
15	oligonucleotide F152	gca gct tct ggc ttc acc att ant nnt nnn ngg ata cac tgg gtg cgt cag	92
16	oligonucleotide F175	gca gct tct ggc ttc acc att ant nnn nnn nnt ata cac tgg gtg cgt cag	92
17	oligonucleotide F176	gca gct tct ggc ttc acc att ant nnn nnn ngg ata cac tgg gtg cgt cag	92
18	oligonucleotide F153	aag ggc ctg gaa tgg gtt gnt ngg att nnt cct nnt nnc ggc nnt act nac tat gcc gat agc gtc aag ggc	92
19	oligonucleotide F154	aag ggc ctg gaa tgg gtt gnt nnt att nnt cct nnt nnc ggc nnt act nac tat gcc gat agc gtc aag ggc	92
20	oligonucleotide F173	agg gcc ctg gaa tgg gtt gnt ngg att nnt cct nnt nnc ggc nnt act nac tat gcc gat agc gtc aag ggc	92
21	oligonucleotide F174	aag ggc ctg gaa tgg gtt gnt nnt att nnt cct nnt nnc ggc nnt act nac tat gcc gat agc gtc aag ggc	92

22	oligonucleotide F125	cgn ttc act ata agc cgt gac aca tcc aaa aac	92
23	single chain Fv		Figure 14
24	single chain Fv with zipper domain		Figure 15
25	Fab fragment		Figure 16
26	Fab fragment with zipper domain		Figure 17
27	hinge sequence	TCPPCPAPELLG	97
28	Fab phagemid vector pV0350-2b		Figure 37
29	F(ab)' <sub>2</sub> phagemid vector pV0350-4		Figure 38
30	oligonucleotide F61	gca act tat tac tgt cag caa nnt nnt nnn nnn cct tnn acg ttc gga cag ggt acc	120
31	F59	SRWGGDGFYAMDY	Figure 4
32	F78	SRXXXXXXFDY	Figure 4
33	F165	AXXXXXXXXXYAMDY	Figure 4
34	F166	AXWXXXXXXXXAMDY	Figure 4
35	F134	AXXXXXXXXXYAMDY	Figure 4
36	F136	AXWXXXXXXXXYAMDY	Figure 4
37	F137	AXXWXXXXXXXXYAMDY	Figure 4
38	F138	AXXXWXXXXXXXXYAMDY	Figure 4
39	F142	AXXXXXXWYAMDY	Figure 4
40	F155	AXWXXXXXXXXXXAMY	Figure 4
41	F156	AXXWXXXXXXXXXAMDY	Figure 4
42	F157	AXXXWXXXXXXXXXAMDY	Figure 4
43	F158	AXXXXWXXXXXXXXXAMDY	Figure 4
44	F160	AXXXXXXWXXAMDY	Figure 4
45	F160g	AXXXXXXXWXAMDY	Figure 4
46	F163a	AXXXXXXXXAMDY	Figure 4
47	F164a	ARXXXXXXXXXYAMDY	Figure 4
48	F164b	ARXXXXXXXXXAMDY	Figure 4
49	F165a	ARXXXXXXXXXYAMDY	Figure 4
50	F165b	ARXXXXXXXXXAMDY	Figure 4
51	F155	AXWXXXXXXXXXXAMY	Figure 4
52	F167	AXWXXXXXXXXXAMDY	Figure 4
53	F135	AXWXXXXXXXXXAMDY	Figure 4
54	F103	SRXXXXXXXXXYAMDY	Figure 4
55	F66a	ARXXXXXXXXYAMDY	Figure 4
56	F66b	ARXXXXXXXXXAMDY	Figure 4
57	F66c	ARXXXXXYXMDY	Figure 4
58	F66d	ARXXXXXXXXXMDY	Figure 4
59	F66e	ARXXXXYXMDY	Figure 4
60	F66f	ARXXXXXXXXMDY	Figure 4
61	F66a1	ARXXXXXXXXYXMDY	Figure 4

62	F66b1	ARXXXXXXXXXMDY	Figure 4
63	F66g	ARXXXXXXXXXMDY	Figure 4
64	F66h	ARXXXXXXXXYXMDY	Figure 4
65	F66i	ARXXXXXXXXXYXMDY	Figure 4
66	F66j	ARXXXXXXXXXMDY	Figure 4
67	F171c	AXXXXXXXFDY	Figure 4
68	F171d	AXXXXXXXFDY	Figure 4
69	F171e	AXXXXXXXFDY	Figure 4
70	F171	AXXXXXXXFDY	Figure 4
71	F186	AXXXXXXXFDY	Figure 4
72	F187	AXXXXXXXFDY	Figure 4
73	F190	AXXXXXXXXXXYAMD	Figure 4
74	F190a	AXXXXXXXXXXYXMD	Figure 4
75	F190d	AXXXXXXXXXXYXMD	Figure 4
76	4D5 CDRH3	WGGDGFY	Figure 4
77	CDRH3	SRWKYATRYAM	Figure 29
78	CDRH3	SRSRGWTAAM	Figure 29
79	CDRH3	SRASRDWYGAM	Figure 29
80	mVEGF-201 CDRH1	TTSNG	Figure 33
81	mVEGF-201 CDRH2	AYSSNYR	Figure 33
82	mVEGF-201 CDRH3	ARWSRASFY	Figure 33
83	mVEGF-202 CDRH1	TTGTD	Figure 33
84	mVEGF-202 CDRH2	AITYDSYR	Figure 33
85	mVEGF-202 CDRH3	AKAGDREGY	Figure 33
86	mVEGF-203 CDRH1	TTDSG	Figure 33
87	mVEGF-203 CDRH2	GRSYSSNR	Figure 33
88	mVEGF-203 CDRH3	AKWPWYNAW	Figure 33
89	hFc-10 CDRH1	TNNYW	Figure 33
90	hFc-10 CDRH2	GYSYGTR	Figure 33
91	hFc-10 CDRH3	AKAXKGSLY	Figure 33
92	hFc-11 CDRH1	TTGNA	Figure 33
93	hFc-12 CDRH1	TNDYY	Figure 33
94	hFc-13 CDRH1	TSNTG	Figure 33
95	hFc-14 CDRH1	TTSYG	Figure 33
96	hFc-14 CDRH2	ASSYSYR	Figure 33
97	hFc-14 CDRH3	AKYXAREGX	Figure 33
98	hFc-15 CDRH1	TNNNS	Figure 33
99	hFc-15 CDRH2	GYNSGSR	Figure 33
100	hFc-15 CDRH3	AKWRTSWKY	Figure 33
101	hFc-16 CDRH1	TSSSA	Figure 33

102	hFc-16 CDRH2	AWSNGSR	Figure 33
103	hFc-16 CDRH3	AXTAGGAKY	Figure 33
104	hFc-17 CDRH1	TTNTW	Figure 33
105	hFc-17 CDRH2	GDYDGYR	Figure 33
106	hFc-17 CDRH3	AXWRWWGRY	Figure 33
107	hFc-18 CDRH1	TNGNY	Figure 33
108	hFc-18 CDRH2	GWSNGYR	Figure 33
109	hFc-18 CDRH3	ARYSGGRRY	Figure 33
110	hFc-19 CDRH1	TSNNA	Figure 33
111	hFc-19 CDRH2	GRSYNYR	Figure 33
112	hFc-19 CDRH3	AXGXTSGGY	Figure 33
113	hFc-20 CDRH1	TTSND	Figure 33
114	hFc-20 CDRH2	AWSYNYR	Figure 33
115	hFc-20 CDRH3	ARRSRWSRA	Figure 33
116	mVEGF-109 CDRH1	TGNSW	Figure 35
117	mVEGF-109 CDRH2	VATYYN	Figure 35
118	mVEGF-109 CDRH3	WGAKGTW	Figure 35
119	mVEGF-126 CDRH1	NADSA	Figure 35
120	mVEGF-126 CDRH2	YAYDYY	Figure 35
121	mVEGF-126 CDRH3	WGWTTNG	Figure 35
122	mVEGF-127 CDRH1	NDNTA	Figure 35
123	mVEGF-127 CDRH2	VSHDTY	Figure 35
124	mVEGF-127 CDRH3	WGWETDG	Figure 35
125	mVEGF-130 CDRH2	LDSSYD	Figure 35
126	mVEGF-130 CDRH3	SRAGYTY	Figure 35
127	mVEGF-136 CDRH1	NGKSS	Figure 35
128	mVEGF-136 CDRH2	WSYEAA	Figure 35
129	mVEGF-136 CDRH3	TSWSKPY	Figure 35
130	mVEGF-169 CDRH1	NTAYG	Figure 35
131	mVEGF-169 CDRH2	VTYDDT	Figure 35
132	mVEGF-169 CDRH3	WGWEANW	Figure 35

133	mVEGF-173 CDRH1	TGGSW	Figure 35
134	mVEGF-173 CDRH2	VYTYD	Figure 35
135	mVEGF-173 CDRH3	WGAGGTW	Figure 35
136	mVEGF-174 CDRH2	VSDYYD	Figure 35
137	mVEGF-174 CDRH3	WGSgyTW	Figure 35
138	mVEGF-176 CDRH1	SAGYD	Figure 35
139	mVEGF-176 CDRH2	LAYAYN	Figure 35
140	mVEGF-176 CDRH3	AAAWASY	Figure 35
141	mVEGF-179 CDRH1	TTESG	Figure 35
142	mVEGF-179 CDRH2	VYHDKY	Figure 35
143	mVEGF-179 CDRH3	WWYSWNW	Figure 35
144	F183	AXXXXXXYAMDY	Figure 43
145	F184	AXXXXXXAMDY	Figure 43
146	F190f	AXXXXXXXXXXMDY	Figure 43
147	F190n	AXXXXXXXXXYXMDY	Figure 43
148	F187b	ARXXXXXXXXXXDY	Figure 43
149	F181	AXXXXXXXXXXAMDY	Figure 43
150	F190j	AXXXXXXXXXXMDY	Figure 43
151	F190q	AXXXXXXXXXYXMDY	Figure 43
152	F187c	ARXXXXXXXXXXDY	Figure 43
153	F179	AXXXXXXXXXXYAMDY	Figure 43
154	F182	AXXXXXXXXXXAMDY	Figure 43
155	F190g	ARXXXXXXXXXXXXXMDY	Figure 43
156	F190k	ARXXXXXXXXXXXYXMDY	Figure 43
157	F190h	ARXXXXXXXXXXXXXMDY	Figure 43
158	F190m	ARXXXXXXXXXXXYXMDY	Figure 43
159	F190i	ARXXXXXXXXXXXXXMDY	Figure 43
160	F190p	ARXXXXXXXXXXXYXMDY	Figure 43
161	F190r	ARXXXXXXXXXXXYXMDY	Figure 43
162	F59	SRWGXXXXXAMDY	Figure 4
163	C-terminal of CDRH3	YAMDY	64
164	CDRH3	(X) <sub>n</sub> XAMDY where n = 4 to 14	72

## DETAILED DESCRIPTION OF THE INVENTION

The invention provides novel and systematic methods for diversifying antibody variable domain sequences, and libraries comprising a multiplicity, generally a great multiplicity of diversified antibody variable domain sequences.

5 Such libraries provide combinatorial libraries useful for, for example, selecting and/or screening for synthetic antibody clones with desirable activities such as binding affinities and avidities. These libraries are useful for identifying immunoglobulin polypeptide sequences that are capable of interacting with any of a wide variety of target antigens. For example, libraries comprising diversified

10 immunoglobulin polypeptides of the invention expressed as phage displays are particularly useful for, and provide a high throughput, efficient and automatable systems of, selecting and/or screening for antigen binding molecules of interest. The methods of the invention are designed to provide high affinity binders to target antigens with minimal changes to a source or template molecule and provide for

15 good production yields when the antibody or antigens binding fragments are produced in cell culture.

## DEFINITIONS

Amino acids are represented herein as either a single letter code or as the

20 three letter code or both.

The term "affinity purification" means the purification of a molecule based on a specific attraction or binding of the molecule to a chemical or binding partner to form a combination or complex which allows the molecule to be separated from impurities while remaining bound or attracted to the partner moiety.

25 The term "antibody" is used in the broadest sense and specifically covers single monoclonal antibodies (including agonist and antagonist antibodies), antibody compositions with polyepitopic specificity, affinity matured antibodies, humanized antibodies, chimeric antibodies, as well as antigen binding fragments (*e.g.*, Fab, F(ab')<sub>2</sub>, scFv and Fv), so long as they exhibit the desired biological activity.

30 As used herein, "antibody variable domain" refers to the portions of the light and heavy chains of antibody molecules that include amino acid sequences of Complementarity Determining Regions (CDRs; *ie.*, CDR1, CDR2, and CDR3), and Framework Regions (FRs). V<sub>H</sub> refers to the variable domain of the heavy chain. V<sub>L</sub> refers to the variable domain of the light chain. According to the methods used in

this invention, the amino acid positions assigned to CDRs and FRs may be defined according to Kabat (Sequences of Proteins of Immunological Interest (National Institutes of Health, Bethesda, Md., 1987 and 1991)). Amino acid numbering of antibodies or antigen binding fragments is also according to that of Kabat.

5           As used herein, the term "Complementarity Determining Regions (CDRs; ie., CDR1, CDR2, and CDR3) refers to the amino acid residues of an antibody variable domain the presence of which are necessary for antigen binding. Each variable domain typically has three CDR regions identified as CDR1, CDR2 and CDR3. Each complementarity determining region may comprise amino acid  
10 residues from a "complementarity determining region" as defined by Kabat (*i.e.* about residues 24-34 (L1), 50-56 (L2) and 89-97 (L3) in the light chain variable domain and 31-35 (H1), 50-65 (H2) and 95-102 (H3) in the heavy chain variable domain; Kabat *et al.*, *Sequences of Proteins of Immunological Interest*, 5th Ed. Public Health Service, National Institutes of Health, Bethesda, MD. (1991)) and/or  
15 those residues from a "hypervariable loop" (*i.e.* about residues 26-32 (L1), 50-52 (L2) and 91-96 (L3) in the light chain variable domain and 26-32 (H1), 53-55 (H2) and 96-101 (H3) in the heavy chain variable domain; Chothia and Lesk *J. Mol. Biol.* 196:901-917 (1987)). In some instances, a complementarity determining region can include amino acids from both a CDR region defined according to Kabat and a  
20 hypervariable loop. For example, the CDRH1 of the heavy chain of antibody 4D5 includes amino acids 26 to 35.

"Framework regions" (hereinafter FR) are those variable domain residues other than the CDR residues. Each variable domain typically has four FRs identified as FR1, FR2, FR3 and FR4. If the CDRs are defined according to Kabat, the light  
25 chain FR residues are positioned at about residues 1-23 (LCFR1), 35-49 (LCFR2), 57-88 (LCFR3), and 98-107 (LCFR4) and the heavy chain FR residues are positioned about at residues 1-30 (HCFR1), 36-49 (HCFR2), 66-94 (HCFR3), and 103-113 (HCFR4) in the heavy chain residues. If the CDRs comprise amino acid residues from hypervariable loops, the light chain FR residues are positioned about  
30 at residues 1-25 (LCFR1), 33-49 (LCFR2), 53-90 (LCFR3), and 97-107 (LCFR4) in the light chain and the heavy chain FR residues are positioned about at residues 1-25 (HCFR1), 33-52 (HCFR2), 56-95 (HCFR3), and 102-113 (HCFR4) in the heavy chain residues. In some instances, when the CDR comprises amino acids from both a CDR as defined by Kabat and those of a hypervariable loop, the FR residues will

be adjusted accordingly. For example, when CDRH1 includes amino acids H26-H35, the heavy chain FR1 residues are at positions 1-25 and the FR2 residues are at positions 36-49.

As used herein, "codon set" refers to a set of different nucleotide triplet  
5 sequences used to encode desired variant amino acids. A set of oligonucleotides can be synthesized, for example, by solid phase synthesis, including sequences that represent all possible combinations of nucleotide triplets provided by the codon set and that will encode the desired group of amino acids. A standard form of codon designation is that of the IUB code, which is known in the art and described herein.  
10 A codon set typically is represented by 3 capital letters in italics, eg. *NNK*, *NNS*, *XYZ*, *DVK* and the like. A "non-random codon set", as used herein, thus refers to a codon set that encodes select amino acids that fulfill partially, preferably completely, the criteria for amino acid selection as described herein. Synthesis of oligonucleotides with selected nucleotide "degeneracy" at certain positions is well  
15 known in that art, for example the TRIM approach (Knappek et al.; J. Mol. Biol. (1999), 296:57-86); Garrard & Henner, Gene (1993), 128:103). Such sets of oligonucleotides having certain codon sets can be synthesized using commercial nucleic acid synthesizers (available from, for example, Applied Biosystems, Foster City, CA), or can be obtained commercially (for example, from Life Technologies,  
20 Rockville, MD). Therefore, a set of oligonucleotides synthesized having a particular codon set will typically include a plurality of oligonucleotides with different sequences, the differences established by the codon set within the overall sequence. Oligonucleotides, as used according to the invention, have sequences that allow for hybridization to a variable domain nucleic acid template and also can, but does not  
25 necessarily, include restriction enzyme sites useful for, for example, cloning purposes.

An "Fv" fragment is an antibody fragment which contains a complete antigen recognition and binding site. This region consists of a dimer of one heavy and one light chain variable domain in tight association, which can be covalent in nature, for  
30 example in scFv. It is in this configuration that the three CDRs of each variable domain interact to define an antigen binding site on the surface of the  $V_H$ - $V_L$  dimer. Collectively, the six CDRs or a subset thereof confer antigen binding specificity to the antibody. However, even a single variable domain (or half of an Fv comprising



only three CDRs specific for an antigen) has the ability to recognize and bind antigen, although usually at a lower affinity than the entire binding site.

The "Fab" fragment contains a variable and constant domain of the light chain and a variable domain and the first constant domain (CH1) of the heavy chain.

5 F(ab')<sub>2</sub> antibody fragments comprise a pair of Fab fragments which are generally covalently linked near their carboxy termini by hinge cysteines between them. Other chemical couplings of antibody fragments are also known in the art.

"Single-chain Fv" or "scFv" antibody fragments comprise the V<sub>H</sub> and V<sub>L</sub> domains of antibody, wherein these domains are present in a single polypeptide chain. Generally the Fv polypeptide further comprises a polypeptide linker between  
10 the V<sub>H</sub> and V<sub>L</sub> domains, which enables the scFv to form the desired structure for antigen binding. For a review of scFv, see Pluckthun in *The Pharmacology of Monoclonal Antibodies*, Vol 113, Rosenberg and Moore eds. Springer-Verlag, New York, pp. 269-315 (1994).

15 The term "diabodies" refers to small antibody fragments with two antigen-binding sites, which fragments comprise a heavy chain variable domain (V<sub>H</sub>) connected to a light chain variable domain (V<sub>L</sub>) in the same polypeptide chain (V<sub>H</sub> and V<sub>L</sub>). By using a linker that is too short to allow pairing between the two domains on the same chain, the domains are forced to pair with the complementary  
20 domains of another chain and create two antigen-binding sites. Diabodies are described more fully in, for example, EP 404,097; WO 93/11161; and Hollinger et al., *Proc. Natl. Acad. Sci. USA*, 90:6444-6448 (1993).

The expression "linear antibodies" refers to the antibodies described in Zapata et al., *Protein Eng.*, 8(10):1057-1062 (1995). Briefly, these antibodies  
25 comprise a pair of tandem Fd segments (V<sub>H</sub>-C<sub>H</sub>1-V<sub>H</sub>-C<sub>H</sub>1) which, together with complementary light chain polypeptides, form a pair of antigen binding regions. Linear antibodies can be bispecific or monospecific.

"Cell", "cell line", and "cell culture" are used interchangeably herein and such designations include all progeny of a cell or cell line. Thus, for example, terms  
30 like "transformants" and "transformed cells" include the primary subject cell and cultures derived therefrom without regard for the number of transfers. It is also understood that all progeny may not be precisely identical in DNA content, due to deliberate or inadvertent mutations. Mutant progeny that have the same function or

biological activity as screened for in the originally transformed cell are included. Where distinct designations are intended, it will be clear from the context.

"Control sequences" when referring to expression means DNA sequences necessary for the expression of an operably linked coding sequence in a particular  
5 host organism. The control sequences that are suitable for prokaryotes, for example, include a promoter, optionally an operator sequence, a ribosome binding site, and possibly, other as yet poorly understood sequences. Eukaryotic cells are known to utilize promoters, polyadenylation signals, and enhancers.

The term "coat protein" means a protein, at least a portion of which is present  
10 on the surface of the virus particle. From a functional perspective, a coat protein is any protein which associates with a virus particle during the viral assembly process in a host cell, and remains associated with the assembled virus until it infects another host cell. The coat protein may be the major coat protein or may be a minor coat protein. A "major" coat protein is generally a coat protein which is present in the  
15 viral coat at preferably at least about 5, more preferably at least about 7, even more preferably at least about 10 copies of the protein or more. A major coat protein may be present in tens, hundreds or even thousands of copies per virion. An example of a major coat protein is the p8 protein of filamentous phage.

The "detection limit" for a chemical entity in a particular assay is the  
20 minimum concentration of that entity which can be detected above the background level for that assay. For example, in the phage ELISA, the "detection limit" for a particular phage displaying a particular antigen binding fragment is the phage concentration at which the particular phage produces an ELISA signal above that produced by a control phage not displaying the antigen binding fragment.

25 A "fusion protein" and a "fusion polypeptide" refers to a polypeptide having two portions covalently linked together, where each of the portions is a polypeptide having a different property. The property may be a biological property, such as activity *in vitro* or *in vivo*. The property may also be a simple chemical or physical property, such as binding to a target antigen, catalysis of a reaction, etc. The two  
30 portions may be linked directly by a single peptide bond or through a peptide linker containing one or more amino acid residues. Generally, the two portions and the linker will be in reading frame with each other. Preferably, the two portions of the polypeptide are obtained from heterologous or different polypeptides.

"Heterologous DNA" is any DNA that is introduced into a host cell. The DNA may be derived from a variety of sources including genomic DNA, cDNA, synthetic DNA and fusions or combinations of these. The DNA may include DNA from the same cell or cell type as the host or recipient cell or DNA from a different cell type, for example, from a mammal or plant. The DNA may, optionally, include marker or selection genes, for example, antibiotic resistance genes, temperature resistance genes, etc.

As used herein, "highly diverse position" refers to a position of an amino acid located in the variable regions of the light and heavy chains that have a number of different amino acid represented at the position when the amino acid sequences of known and/or naturally occurring antibodies or antigen binding fragments are compared. The highly diverse positions are typically in the CDR regions. In one aspect, the ability to determine highly diverse positions in known and/or naturally occurring antibodies is facilitated by the data provided by Kabat, Sequences of Proteins of Immunological Interest (National Institutes of Health, Bethesda, Md., 1987 and 1991). An internet-based database located at <http://immuno/bme/nwu/edu> provides an extensive collection and alignment of human light and heavy chain sequences and facilitates determination of highly diverse positions in these sequences. According to the invention, an amino acid position is highly diverse if it has preferably from about 2 to about 11, preferably from about 4 to about 9, and preferably from about 5 to about 7 different possible amino acid residue variations at that position. In some embodiments, an amino acid position is highly diverse if it has preferably at least about 2, preferably at least about 4, preferably at least about 6, and preferably at least about 8 different possible amino acid residue variations at that position.

As used herein, "library" refers to a plurality of antibody or antibody fragment sequences (for example, polypeptides of the invention), or the nucleic acids that encode these sequences, the sequences being different in the combination of variant amino acids that are introduced into these sequences according to the methods of the invention.

"Ligation" is the process of forming phosphodiester bonds between two nucleic acid fragments. For ligation of the two fragments, the ends of the fragments must be compatible with each other. In some cases, the ends will be directly compatible after endonuclease digestion. However, it may be necessary first to

convert the staggered ends commonly produced after endonuclease digestion to blunt ends to make them compatible for ligation. For blunting the ends, the DNA is treated in a suitable buffer for at least 15 minutes at 15°C with about 10 units of the Klenow fragment of DNA polymerase I or T4 DNA polymerase in the presence of the four deoxyribonucleotide triphosphates. The DNA is then purified by phenol-chloroform extraction and ethanol precipitation or by silica purification. The DNA fragments that are to be ligated together are put in solution in about equimolar amounts. The solution will also contain ATP, ligase buffer, and a ligase such as T4 DNA ligase at about 10 units per 0.5 µg of DNA. If the DNA is to be ligated into a vector, the vector is first linearized by digestion with the appropriate restriction endonuclease(s). The linearized fragment is then treated with bacterial alkaline phosphatase or calf intestinal phosphatase to prevent self-ligation during the ligation step.

A "mutation" is a deletion, insertion, or substitution of a nucleotide(s) relative to a reference nucleotide sequence, such as a wild type sequence.

As used herein, "natural" or "naturally occurring" antibodies, refers to antibodies identified from a nonsynthetic source, for example, from a differentiated antigen-specific B cell obtained *ex vivo*, or its corresponding hybridoma cell line, or from antibodies obtained from the serum of an animal. These antibodies can include antibodies generated in any type of immune response, either natural or otherwise induced. Natural antibodies include the amino acid sequences, and the nucleotide sequences that constitute or encode these antibodies, for example, as identified in the Kabat database. As used herein, natural antibodies are different than "synthetic antibodies", synthetic antibodies referring to antibody sequences that have been changed from a source or template sequence, for example, by the replacement, deletion, or addition, of an amino acid, or more than one amino acid, at a certain position with a different amino acid, the different amino acid providing an antibody sequence different from the source antibody sequence.

"Operably linked" when referring to nucleic acids means that the nucleic acids are placed in a functional relationship with another nucleic acid sequence. For example, DNA for a presequence or secretory leader is operably linked to DNA for a polypeptide if it is expressed as a preprotein that participates in the secretion of the polypeptide; a promotor or enhancer is operably linked to a coding sequence if it affects the transcription of the sequence; or a ribosome binding site is operably

linked to a coding sequence if it is positioned so as to facilitate translation.

Generally, "operably linked" means that the DNA sequences being linked are contiguous and, in the case of a secretory leader, contingent and in reading frame.

However, enhancers do not have to be contiguous. Linking is accomplished by  
5 ligation at convenient restriction sites. If such sites do not exist, the synthetic oligonucleotide adapters or linkers are used in accord with conventional practice.

"Phage display" is a technique by which variant polypeptides are displayed as fusion proteins to at least a portion of coat protein on the surface of phage, *e.g.*, filamentous phage, particles. A utility of phage display lies in the fact that large  
10 libraries of randomized protein variants can be rapidly and efficiently sorted for those sequences that bind to a target antigen with high affinity. Display of peptide and protein libraries on phage has been used for screening millions of polypeptides for ones with specific binding properties. Polyvalent phage display methods have been used for displaying small random peptides and small proteins through fusions  
15 to either gene III or gene VIII of filamentous phage. Wells and Lowman, *Curr. Opin. Struct. Biol.*, 3:355-362 (1992), and references cited therein. In monovalent phage display, a protein or peptide library is fused to a gene III or a portion thereof, and expressed at low levels in the presence of wild type gene III protein so that phage particles display one copy or none of the fusion proteins. Avidity effects are  
20 reduced relative to polyvalent phage so that sorting is on the basis of intrinsic ligand affinity, and phagemid vectors are used, which simplify DNA manipulations. Lowman and Wells, *Methods: A companion to Methods in Enzymology*, 3:205-0216 (1991).

A "phagemid" is a plasmid vector having a bacterial origin of replication,  
25 *e.g.*, ColE1, and a copy of an intergenic region of a bacteriophage. The phagemid may be used on any known bacteriophage, including filamentous bacteriophage and lambdoid bacteriophage. The plasmid will also generally contain a selectable marker for antibiotic resistance. Segments of DNA cloned into these vectors can be propagated as plasmids. When cells harboring these vectors are provided with all  
30 genes necessary for the production of phage particles, the mode of replication of the plasmid changes to rolling circle replication to generate copies of one strand of the plasmid DNA and package phage particles. The phagemid may form infectious or non-infectious phage particles. This term includes phagemids which contain a phage coat protein gene or fragment thereof linked to a heterologous polypeptide

gene as a gene fusion such that the heterologous polypeptide is displayed on the surface of the phage particle.

The term "phage vector" means a double stranded replicative form of a bacteriophage containing a heterologous gene and capable of replication. The phage vector has a phage origin of replication allowing phage replication and phage particle formation. The phage is preferably a filamentous bacteriophage, such as an M13, f1, fd, Pf3 phage or a derivative thereof, or a lambdoid phage, such as lambda, 21, phi80, phi81, 82, 424, 434, etc., or a derivative thereof.

"Oligonucleotides" are short-length, single- or double-stranded polydeoxynucleotides that are chemically synthesized by known methods (such as phosphotriester, phosphite, or phosphoramidite chemistry, using solid-phase techniques such as described in EP 266,032 published 4 May 1988, or via deoxynucleoside H-phosphonate intermediates as described by Froehner et al., *Nucl. Acids, Res.*, 14:5399-5407 (1986)). Further methods include the polymerase chain reaction defined below and other autoprimer methods and oligonucleotide syntheses on solid supports. All of these methods are described in Engels et al., *Angew. Chem. Int. Ed. Engl.*, 28:716-734 (1989). These methods are used if the entire nucleic acid sequence of the gene is known, or the sequence of the nucleic acid complementary to the coding strand is available. Alternatively, if the target amino acid sequence is known, one may infer potential nucleic acid sequences using known and preferred coding residues for each amino acid residue. The oligonucleotides can be purified on polyacrylamide gels or molecular sizing columns or by precipitation.

DNA is "purified" when the DNA is separated from non-nucleic acid impurities. The impurities may be polar, non-polar, ionic, etc.

A "source antibody", as used herein, refers to an antibody or antigen binding fragment whose antigen binding sequence serves as the template sequence upon which diversification according to the criteria described herein is performed. An antigen binding sequence generally includes an antibody variable region, preferably at least one CDR, preferably including framework regions.

As used herein, "solvent accessible position" refers to a position of an amino acid residue in the variable regions of the heavy and light chains of a source antibody or antigen binding fragment that is determined, based on structure, ensemble of structures and/or modeled structure of the antibody or antigen binding fragment, as potentially available for solvent access and/or contact with a molecule,

such as an antibody-specific antigen. These positions are typically found in the CDRs and on the exterior of the protein. The solvent accessible positions of an antibody or antigen binding fragment, as defined herein, can be determined using any of a number of algorithms known in the art. Preferably, solvent accessible positions are determined using coordinates from a 3-dimensional model of an antibody, preferably using a computer program such as the InsightII program (Accelrys, San Diego, CA). Solvent accessible positions can also be determined using algorithms known in the art (e.g., Lee and Richards, *J. Mol. Biol.* 55, 379 (1971) and Connolly, *J. Appl. Cryst.* 16, 548 (1983)). Determination of solvent accessible positions can be performed using software suitable for protein modeling and 3-dimensional structural information obtained from an antibody. Software that can be utilized for these purposes includes SYBYL Biopolymer Module software (Tripos Associates). Generally and preferably, where an algorithm (program) requires a user input size parameter, the "size" of a probe which is used in the calculation is set at about 1.4 Angstrom or smaller in radius. In addition, determination of solvent accessible regions and area methods using software for personal computers has been described by Pacios ((1994) "ARVOMOL/CONTOUR: molecular surface areas and volumes on Personal Computers." *Comput. Chem.* 18(4): 377-386; and (1995). "Variations of Surface Areas and Volumes in Distinct Molecular Surfaces of Biomolecules." *J. Mol. Model.* 1: 46-53.)

As used herein, "target amino acid" refers to an amino acid that belongs to the group of amino acids that are collectively the most commonly occurring amino acids found at a particular position of known and/or natural occurring antibodies or antigen binding fragments. In some embodiments, the most commonly occurring amino acids" are those amino acids that are found in a particular position in preferably at least about 50%, preferably at least about 70%, preferably at least about 80%, preferably at least about 90%, preferably all of sequences of known and/or natural antibodies or antigen binding fragments. In some embodiments, the most commonly occurring amino acids" are those amino acids that are found in a particular position in preferably from about 50% to about 100%, preferably from about 60% to about 90%, preferably from about 70% to about 85%, preferably from about 80% to about 85% of the sequences of known and/or natural antibodies or antigen binding fragments. Known antibodies or antigen binding fragments are

those whose sequences are available in the art, such as those available in publicly-accessible databases, such as the database of Kabat ("Sequence of Proteins of Immunological Interest, National Institutes of Health, Bethesda, Md., 1987 and 1991) and/or as located at <http://immuno/bme/nwu/edu>. The amino acid position is preferably a position in the CDR region. A target group of amino acids refers to a group of target amino acids for a particular position. Preferably, a target amino acid is not a cysteine residue. For positions in the light chain CDR1, CDR2, CDR3, and for heavy chain CDR1 and CDR2, typically, a target group of amino acids can include from preferably about 2 to about 11, preferably from about 4 to about 9, preferably from about 5 to about 7, preferably about 6 amino acids at a particular highly diverse and solvent-accessible position of the source sequence.

A "transcription regulatory element" will contain one or more of the following components: an enhancer element, a promoter, an operator sequence, a repressor gene, and a transcription termination sequence. These components are well known in the art. U.S. Patent No. 5,667,780.

A "transformant" is a cell which has taken up and maintained DNA as evidenced by the expression of a phenotype associated with the DNA (e.g., antibiotic resistance conferred by a protein encoded by the DNA).

"Transformation" means a process whereby a cell takes up DNA and becomes a "transformant". The DNA uptake may be permanent or transient.

A "variant" or "mutant" of a starting or reference polypeptide (for e.g., a source antibody or its variable domain(s)/CDR(s)), such as a fusion protein (polypeptide) or a heterologous polypeptide (heterologous to a phage), is a polypeptide that 1) has an amino acid sequence different from that of the starting or reference polypeptide and 2) was derived from the starting or reference polypeptide through either natural or artificial (manmade) mutagenesis. Such variants include, for example, deletions from, and/or insertions into and/or substitutions of, residues within the amino acid sequence of the polypeptide of interest. For example, a fusion polypeptide of the invention generated using an oligonucleotide comprising a nonrandom codon set that encodes a sequence with a variant amino acid (with respect to the amino acid found at the corresponding position in a source antibody/antigen binding fragment) would be a variant polypeptide with respect to a source antibody or antigen binding fragment. Thus, a variant CDR refers to a CDR comprising a variant sequence with respect to a starting or reference polypeptide



sequence (such as that of a source antibody or antigen binding fragment). A variant amino acid, in this context, refers to an amino acid different from the amino acid at the corresponding position in a starting or reference polypeptide sequence (such as that of a source antibody or antigen binding fragment). Any combination of  
5 deletion, insertion, and substitution may be made to arrive at the final variant or mutant construct, provided that the final construct possesses the desired functional characteristics. - The amino acid changes also may alter post-translational processes of the polypeptide, such as changing the number or position of glycosylation sites. Methods for generating amino acid sequence variants of polypeptides are described  
10 in U.S. Patent No. 5,534,615, expressly incorporated herein by reference.

A "wild type" or "reference" sequence or the sequence of a "wild type" or "reference" protein/polypeptide, such as a coat protein, or a CDR or variable domain of a source antibody, maybe the reference sequence from which variant polypeptides are derived through the introduction of mutations. In general, the "wild type"  
15 sequence for a given protein is the sequence that is most common in nature. Similarly, a "wild type" gene sequence is the sequence for that gene which is most commonly found in nature. Mutations may be introduced into a "wild type" gene (and thus the protein it encodes) either through natural processes or through man induced means. The products of such processes are "variant" or "mutant" forms of  
20 the original "wild type" protein or gene.

A "plurality" of a substance, such as a polypeptide or polynucleotide of the invention, as used herein, generally refers to a collection of two or more types or kinds of the substance. There are two or more types or kinds of a substance if two or more of the substances differ from each other with respect to a particular  
25 characteristic, such as the variant amino acid found at a particular amino acid position. For example, there is a plurality of polypeptides of the invention if there are two or more polypeptides of the invention that are substantially the same, preferably identical, in sequence except for the sequence of a variant CDR or except for the variant amino acid at a particular solvent accessible and highly diverse amino  
30 acid position. In another example, there is a plurality of polynucleotides of the invention if there are two or more polynucleotides of the invention that are substantially the same, preferably identical, in sequence except for the sequence that encodes a variant CDR or except for the sequence that encodes a variant amino acid for a particular solvent accessible and highly diverse amino acid position.

The invention provides methods for generating and isolating novel antibodies or antigen binding fragments that preferably have a high affinity for a selected antigen. A plurality of different antibodies or antibody variable domains are prepared by mutating (diversifying) one or more selected amino acid positions in a source antibody light chain variable domain and/or heavy chain variable domain to generate a diverse library of antibody variable domains with variant amino acids at those positions. The amino acid positions are those that are solvent accessible, for example as determined by analyzing the structure of a source antibody, and/or that are highly diverse among known and/or natural occurring immunoglobulin polypeptides.

The amino acid positions that are solvent accessible and highly diverse are preferably those in the CDR regions of the antibody variable domains selected from the group consisting of CDRL1, CDRL2, CDRL3, CDRH1, CDRH2, CDRH3, and mixtures thereof. Amino acid positions are each mutated using a non-random codon set encoding the commonly occurring amino acids at each position. In some embodiments, when a solvent accessible and highly diverse position in a CDR region is to be mutated, a codon set is selected that encodes preferably at least about 50%, preferably at least about 60%, preferably at least about 70%, preferably at least about 80%, preferably at least about 90%, preferably all the target amino acids (as defined above) for that position. In some embodiments, when a solvent accessible and highly diverse position in a CDR region is to be mutated, a codon set is selected that encodes preferably from about 50% to about 100%, preferably from about 60% to about 95%, preferably from at least about 70% to about 90%, preferably from about 75% to about 90% of all the target amino acids (as defined above) for that position. For CDRH3, variant CDRH3 regions are generated that have different lengths and/or are randomized at selected positions using codons set such as *NNK*, *NNS*, *NVT*, *DVK*, *XYZ* or tryptophan or glycine or mixtures thereof.

The diversity of the library of the antibody variable domains is designed to maximize diversity while minimizing structural perturbations of the antibody variable domain to provide for increased ability to isolate high affinity antibodies and to provide for antibodies that can be produced in high yield in cell culture. The number of positions mutated in the antibody variable domain is minimized and the variant amino acids at each position are designed to include the commonly occurring amino acids at each position, while preferably (where possible) excluding

uncommonly occurring amino acids. Preferably, a single antibody, including at least one CDR, is used as the source antibody. It is surprising that a library of antibody variable domains having diversity in sequences and size can be generated using a single source antibody as a template and targeting diversity to particular positions using particular amino acid substitutions.

### **Design of Diversity of Antibody Variable Domains**

In one aspect of the invention, high quality libraries of antibody variable domains are generated. The libraries have diversity in number of members of the library as well as in the diversity of different sequences of the antibody variable domains. The libraries include high affinity binding antibody variable domains for one or more antigens, including, for example, insulin like growth factor-1 (IGF-1), vascular endothelial growth factor (VEGF), and Her-2. The diversity in the library is designed by selecting amino acid positions that are solvent accessible and highly diverse in a single source antibody and mutating those positions in at least one CDR using nonrandom codon sets. The nonrandom codon set preferably encodes at least a subset of the commonly occurring amino acids at those positions while minimizing nontarget sequences such as cysteine and stop codons.

A preferred source antibody is humanized antibody 4D5, but the methods for diversity design can be applied to other source antibodies whose sequence is known. A source antibody can be a naturally occurring antibody, synthetic antibody, recombinant antibody, humanized antibody, germ line derived antibody, chimeric antibody, affinity matured antibody, or antigen binding fragment thereof. The antibodies can be obtained from a variety of mammalian species including humans, mice and rats. In some embodiments, a source antibody is an antibody that is obtained after one or more initial affinity screening rounds, but prior to an affinity maturation step(s). A source antibody may be selected or modified to provide for high yield and stability when produced in cell culture.

One source antibody is the humanized antibody 4D5. Antibody 4D5 is a humanized antibody specific for a cancer-associated antigen known as Her-2 (erbB2). The antibody includes variable domains having consensus framework regions; a few positions were reverted to mouse sequence during the process of increasing affinity of the humanized antibody. The sequence and crystal structure of humanized antibody 4D5 have been described in U. S. 6,054,297, Carter et al, PNAS

89:4285 (1992), the crystal structure is shown in J Mol. Biol. 229:969 (1993) and online at [www.ncbi.nlm.nih.gov/structure/mmdb\(MMDB#s-990-992\)](http://www.ncbi.nlm.nih.gov/structure/mmdb(MMDB#s-990-992)).

A criterion for generating diversity in antibody variable domains is to mutate residues at positions that are solvent accessible (as defined above). These positions  
5 are typically found in the CDRs, and are typically on the exterior of the protein. Preferably, solvent accessible positions are determined using coordinates from a 3-dimensional model of an antibody, using a computer program such as the InsightII program (Accelrys, San Diego, CA). Solvent accessible positions can also be determined using algorithms known in the art (e.g., Lee and Richards, J. Mol. Biol.  
10 55, 379 (1971) and Connolly, J. Appl. Cryst. 16, 548 (1983)). Determination of solvent accessible positions can be performed using software suitable for protein modeling and 3-dimensional structural information obtained from an antibody. Software that can be utilized for these purposes includes SYBYL Biopolymer Module software (Tripos Associates). Generally and preferably, where an algorithm  
15 (program) requires a user input size parameter, the "size" of a probe which is used in the calculation is set at about 1.4 Angstrom or smaller in radius. In addition, determination of solvent accessible regions and area methods using software for personal computers has been described by Pacios ((1994)  
"ARVOMOL/CONTOUR: molecular surface areas and volumes on Personal  
20 Computers", *Comput. Chem.* 18(4): 377-386; and "Variations of Surface Areas and Volumes in Distinct Molecular Surfaces of Biomolecules." *J. Mol. Model.* (1995), 1: 46-53).

In some instances, selection of solvent accessible residues is further refined by choosing solvent accessible residues that collectively form a minimum  
25 contiguous patch, for example when the reference polypeptide or source antibody is in its 3-D folded structure. For example, as shown in Figure 36, a compact (minimum) contiguous patch is formed by residues selected for CDRH1/H2/H3/L1/L2/L3 of humanized 4D5. A compact (minimum) contiguous patch may comprise only a subset (for example, 2-5 CDRs) of the full range of  
30 CDRs, for example, CDRH1/H2/H3/L3. Solvent accessible residues that do not contribute to formation of such a patch may optionally be excluded from diversification. Refinement of selection by this criterion permits the practitioner to minimize, as desired, the number of residues to be diversified. For example, residue 28 in H1 can optionally be excluded in diversification since it is on the edge of the

patch. However, this selection criterion can also be used, where desired, to choose residues to be diversified that may not necessarily be deemed solvent accessible. For example, a residue that is not deemed solvent accessible, but forms a contiguous patch in the 3-D folded structure with other residues that are deemed solvent accessible may be selected for diversification. An example of this is CDRL1-29. Selection of such residues would be evident to one skilled in the art, and its appropriateness can also be determined empirically and according to the needs and desires of the skilled practitioner.

The solvent accessible positions identified from the crystal structure of humanized antibody 4D5 for each CDR are as follows (residue position according to Kabat):

CDRL1: 28, 30, 31, 32

CDRL2: 50, 53

CDRL3: 91, 92, 93, 94, 96

CDRH1: 28, 30, 31, 32, 33

CDRH2: 50, 52, 52A, 53, 54, 55, 56, 57, 58.

In addition, residue 29 of CDRL1 was also selected based on its inclusion in a contiguous patch comprising other solvent accessible residues.

Another criterion for selecting positions to be mutated are those positions which show variability in amino acid sequence when the sequences of known and/or natural antibodies are compared. A highly diverse position refers to a position of an amino acid located in the variable regions of the light or heavy chains that have a number of different amino acids represented at the position when the amino acid sequences of known and/or natural antibodies/antigen binding fragments are compared. The highly diverse positions are preferably in the CDR regions. The positions of CDRH3 are all considered highly diverse. According to the invention, amino acid residues are highly diverse if they have preferably from about 2 to about 11 (although the numbers can range as described herein) different possible amino acid residue variations at that position.

In one aspect, identification of highly diverse positions in known and/or naturally occurring antibodies is facilitated by the data provided by Kabat, Sequences of Proteins of Immunological Interest (National Institutes of Health, Bethesda, Md., 1987 and 1991). An internet-based database located at <http://immuno/bme/nwu/edu> provides an extensive collection and alignment of human

light and heavy chain sequences and facilitates determination of highly diverse positions in these sequences. The diversity at the solvent accessible positions of humanized antibody 4D5 in known and/or naturally occurring light and heavy chains is shown in Figures 1 and 2.

5           In one aspect of the invention, the highly diverse and solvent accessible residues in at least one CDR selected from the group consisting of CDRL1, CDRL2, CDRL3, CDRH1, CDRH2 and mixtures thereof are mutated (i.e., randomized using codon sets as described herein). In some embodiments, the group also includes CDRH3. For example, the solvent accessible and/or highly diverse residues in  
10   CDRL3 and CDRH3 are mutated. Accordingly, the invention provides for a large number of novel antibody sequences formed by replacing the solvent accessible and highly diverse positions of at least one CDR of the source antibody variable domain with variant amino acids.

          A target group of amino acids is the group of amino acids found at each  
15   solvent accessible and highly diverse position in a CDR in preferably at least about 50%, preferably at least about 70%, preferably at least about 80%, preferably at least about 90% of antibodies when the sequences of known and/or natural antibodies/antigen binding fragments are compared. The variant amino acids are a group of amino acids that include some or all of the target amino acids and are  
20   encoded by a nonrandom codon set. Of the amino acids encoded by the nonrandom codon set, preferably at least about 70% of the amino acids are target amino acids and more preferably at least about 80% of the amino acids are target amino acids. The nonrandom codon set for each position preferably encodes at least two amino acids and does not encode cysteine. Nontarget amino acids at each position are  
25   minimized and cysteines and stop codons are generally and preferably excluded because they can adversely affect the structure of the antibody variable domain for, in particular, L1, L2, L3, H1 and H2. For positions in the light chain CDR1, CDR2, CDR3, and for heavy chain CDR1 and CDR2, typically, a set of target amino acids can include from about two to eleven amino acids at a particular highly diverse and  
30   solvent-accessible position of the source sequence.

          As discussed above, the variant amino acids are encoded by nonrandom codon sets. A codon set is a set of different nucleotide triplet sequences which can be used to form a set of oligonucleotides used to encode the desired group of amino acids. A set of oligonucleotides can be synthesized, for example, by solid phase

synthesis, containing sequences that represent all possible combinations of nucleotide triplets provided by the codon set and that will encode the desired group of amino acids. Synthesis of oligonucleotides with selected nucleotide "degeneracy" at certain positions is well known in that art. Such sets of nucleotides having certain codon sets can be synthesized using commercial nucleic acid synthesizers (available from, for example, Applied Biosystems, Foster City, CA), or can be obtained commercially (for example, from Life Technologies, Rockville, MD). Therefore, a set of oligonucleotides synthesized having a particular codon set will typically include a plurality of oligonucleotides with different sequences, the differences established by the codon set within the overall sequence. Oligonucleotides, as used according to the invention, have sequences that allow for hybridization to a variable domain nucleic acid template and also can include restriction enzyme sites for cloning purposes.

In one aspect, the target amino acids were identified for each solvent accessible and highly diverse position in CDRs of humanized antibody 4D5. The target amino acids were identified by identifying different amino acids at each of the solvent accessible and highly diverse positions in CDRL1, CDRL2, CDRL3, CDRH1 and CDRH2 using the sequences of known and/or naturally occurring antibodies in the Kabat database. Light chain diversity and heavy chain diversity from the Kabat database are shown in Figures 1 and 2, respectively. Based on the diversity as shown in Figures 1 and 2, the target amino acids identified at each position are shown in Figure 3.

Illustrative nonrandom codon sets encoding a group of amino acids comprising preferably at least about 50%, preferably at least about 60%, preferably at least about 70%, preferably at least about 80%, preferably at least about 90%, preferably all of the target amino acids for each position are also shown in Figure 3. The "% good" in Figure 3 represents the percentage of amino acids encoded by the nonrandom codon set that are target amino acids for that position. Most preferably, the variant amino acids encoded by the codon set include the amino acids occurring with the highest frequency in known and/or naturally occurring antibodies. The high percentage means very low nontarget amino acids and this is more important than having more of the target amino acids in the design of the nonrandom codon set. The redundancy is included in all calculations.

The “% covering” in Figure 3, represents the percentage of known and/or natural occurring antibody sequences that are encoded by the designed codons at each position. For example, for L3-91, the amino acids YSA (tyrosine, serine and alanine) are in the group of target amino acids which occur at position 91 in known and/or naturally occurring antibodies. The codon set is designed to encode YSAD (tyrosine, serine, alanine and aspartic acid), which encodes 75% of the target amino acids. These three amino acids are also found in 1190 out of 1580 natural antibody sequences at that site, which is 75% of the known and/or natural antibodies. It is preferable that codon sets are designed for each position in a CDR region to include amino acids found in those positions in at least about 50% of the known and/or naturally occurring antibodies and more preferably in at least about 60 % of the known and/or naturally occurring antibodies and most preferably in at least about 70 % of the known and/or naturally occurring antibodies.

In one embodiment, a polypeptide having a variant CDR L1, L2, L3, H1, H2 or mixtures thereof is formed, wherein at least one variant CDR comprises a variant amino acid in at least one solvent accessible and highly diverse amino acid position, wherein the variant amino acid is encoded by a nonrandom codon set, and wherein at least 70% of the amino acids encoded by the nonrandom codon set are target amino acids for that position in known antibody variable domain sequences. For example, an antibody variable domain can comprise a variant amino acid in one or more amino acid positions 28, 30, 31, 32 and/or 33 of CDRH1; and/or in one or more amino acid positions 50, 52, 53, 54, 56 and/or 58 of CDRH2; and/or in one or more amino acid positions 28, 29, 30 and/or 31 of CDRL1; and/or in one or more amino acid positions 50 and/or 53 in CDRL2; and/or in one or more amino acid positions 91, 92, 93, 94 and/or 96. The variant amino acids at these positions are preferably encoded by codon sets as exemplified in Figures 3, 5-13 and 24.

Heavy chain CDR3s (CDRH3s) in known antibodies have diverse sequences, structural conformations, and lengths. CDRH3s are often found in the middle of the antigen binding pocket and often participate in antigen contact. The design of CDRH3 is thus preferably developed separately from that of the other CDRs because it can be difficult to predict the structural conformation of CDRH3 and the amino acid diversity in this region is especially diverse in known antibodies. In accordance with the present invention, CDRH3 is designed to generate diversity at



specific positions within CDRH3 and to exclude amino acids which do not occur frequently in CDRH3 sequences at any position.

To generate diversity in CDRH3, a database of known, generally natural, antibodies can be used as a guideline. In comparison to other CDRs, CDRH3 has the highest diversity in sequences and length, although the sequence diversity is not completely random (i.e., some amino acids occur more often than others). In one embodiment, a library is generated with a degenerate codon set such as *NNK*, which codes for all 20 amino acids and a stop codon. Clones that display functionally on the phage are analyzed for their sequences. Frequency of amino acids in the synthetically-generated library is then compared with the frequency of amino acids in known antibodies. Good agreement of amino acid frequency can be expected, although in some instances there may be increased frequency of certain classes of amino acids in the synthetic library compared to known antibodies. For example, a library generated with *NNK* can be expected to contain sequences that utilize more usage of aliphatic/hydrophobic amino acids. This procedure can be performed to obtain useful information on appropriate choice of amino acids, and thus codon sets, to include in generating CDRH3 diversity. In another embodiment, CDRH3 diversity is generated using the codon set *NNS*. *NNS* and *NNK* encode the same amino acid group. However, there can be individual preferences for one codon set or the other, depending on the various factors known in the art, such as efficiency of coupling in oligonucleotide synthesis chemistry.

In some embodiments, the practitioner of methods of the invention may wish to modify the amount/proportions of individual nucleotides (G, A, T, C) for a codon set, such as the N nucleotide in a codon set such as in *NNS*. This is illustratively represented as *XYZ* codons indicated in Figure 4. This can be achieved by, for example, doping different amounts of the nucleotides within a codon set instead of using a straight, equal proportion of the nucleotides for the N in the codon set. For example, a codon set *XYZ* has the following proportions of nucleotides. X is 38% G, 19% A, 26% T and 17% C; Y is 31% G, 34% A, 17% T and 18% C, and Z is 24% G/76% C. Such modifications can be useful for various purposes depending on the circumstances and desire of the practitioner. For example, such modifications can be made to more closely reflect the amino acid bias as seen in a natural diversity profile, such as the profile of CDRH3.

In some embodiments, a diversified CDRH3 library can be generated with a codon set such as *DVK*, which encodes 11 amino acids (ACDEGKNRSYW) and one stop codon. This excludes amino acids that occur infrequently in known antibodies. A CDRH3 library may also be generated using the codon set *NVT*,  
 5 which encodes 11 amino acids (ACDGHNPRSTY), but does not encode stop codons or tryptophan (Trp, W). In some embodiments, the design of a codon set, such as *NVT*, may be doped with Trp.

As discussed previously, there is great diversity in CDRH3 regions in length of the CDRH3 regions. In natural antibodies, lengths of CDRH3 can range from 2  
 10 to 24 amino acids with the most common length being 11-13 residues. In one embodiment, diversity in CDRH3 is generated by preparing a number of different libraries, each library having a different length of CDRH3 region ranging from about 7 to 19 amino acids. The libraries with different lengths of CDRH3 regions are then pooled and used to select and/or screen for high affinity binding antibody variable  
 15 domains. Illustrative embodiments of oligonucleotides that can be utilized to provide for variety in CDRH3 sequence length include those shown in Figure 4 and Figure 43.

In some embodiments, the diversity in the N and C-terminal regions of CDRH3 is minimized. At the C-terminus, there may be two types of sequences in  
 20 known antibodies:  $Y_{100a}AMD_{101}(Y/V)_{102}$  or  $F_{100a}D_{101}(Y/V)_{102}$ . Limited diversity can be targeted at selected residues in the C-terminal region. For example,  $Y_{100a}$  position can be varied using codon sets that encode fewer amino acids such as *DVK*, *DSG*, *KSG*, *DSG*, or may be varied with a codon set that encodes all 20 amino acids such as *NNK*, *NVT*, or *XYZ*.

25 One aspect of the invention provides a polypeptide, such as an antibody variable domain, comprising a variant CDRH3 that comprises an amino acid sequence:

$$(X_1)_n - X_2 - X_3 - X_4 - X_5 - X_6$$

wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*,  
 30 *NNS*, *DVK*, *NVT*, *XYZ* or is tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;

$X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*, *DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine, phenylalanine, serine, alanine, glycine, leucine, or tryptophan;

$X_3$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is alanine, valine, aspartic acid or glycine;

$X_4$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is methionine;

5  $X_5$  is aspartic acid, alanine, valine, or glycine; and

$X_6$  is tyrosine or valine.

A polypeptide or library of polypeptides with variant CDRH3 of the formula as shown above may be generated using any one or combination of the oligonucleotides illustrated in Figure 4 and Figure 43.

10 In one embodiment, CDRH3 comprises an amino acid sequence  $(X_1)_n - X_2 - X_3 - X_4 - X_5 - X_6$ , wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;  $X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*, *DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine,  
15 phenylalanine, serine, glycine, alanine, leucine, or tryptophan;  $X_3$  is alanine, valine, aspartic acid or glycine;  $X_4$  is methionine;  $X_5$  is aspartic acid, alanine, valine, or glycine; and  $X_6$  is tyrosine or valine.

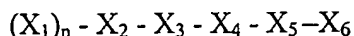
In some embodiments,  $n$  is preferably 4 and  $X_1$  is any naturally occurring amino acid encoded by codon sets *NNK*, *NNS* or *XYZ*,  $X_2$  is any naturally occurring  
20 amino acid encoded by *KSG*, *NNK*, *XYZ* or is tyrosine,  $X_3$  is alanine, glycine or valine,  $X_4$  is methionine,  $X_5$  is aspartic acid and  $X_6$  is tyrosine. A polypeptide or plurality of polypeptides comprising variant CDRH3 region in these embodiments can be generated using at least one or more than one of oligonucleotides F66e and F66f.

25 In some embodiments,  $n$  is preferably 6, and  $X_1$  is any naturally occurring amino acid encoded by codon sets *DVK*, *NVT*, *NNK*, *NNS* or *XYZ* or tryptophan or glycine or mixtures thereof,  $X_2$  is any naturally occurring amino acid encoded by *DSG*, *DVK*, *KSG*, *NNK*, *XYZ* or is tyrosine, glycine, serine, alanine or tryptophan,  $X_3$  is alanine,  $X_4$  is methionine,  $X_5$  is aspartic acid and  $X_6$  is tyrosine. In some  
30 embodiments,  $X_1$  corresponds to amino acid position 95,  $X_2$  corresponds to amino acid position 100a, A is in position 100b, M is in position 100c, D is in position 101 and Y is in position 102 of CDRH3 of antibody 4D5. A polypeptide or plurality of polypeptides comprising a variant CDRH3 region in these embodiments can be generated using at least one or more than one of oligonucleotides F63, F64, F65,

F66, F165, F134, F135, F163a, F166, F167, F66a, F66b, F66a1, F66b1, F190f, and F190n.

In another embodiment, CDRH3 comprises an amino acid sequence  $(X_1)_n - X_2 - X_3 - X_4 - X_5 - X_6$ ; wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or is tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;  $X_2$  is leucine or phenylalanine;  $X_3$  is missing;  $X_4$  is missing;  $X_5$  is aspartic acid, alanine, valine, or glycine; and  $X_6$  is tyrosine or valine. In some embodiments, the variant CDRH3 comprises an amino acid sequence  $(X_1)_n - X_2 - D - Y$ ; wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;  $X_2$  is leucine or phenylalanine; D is aspartic acid and Y is tyrosine. In other embodiments,  $n$  is preferably 6 and  $X_1$  corresponds to amino acid position 95,  $X_2$  corresponds to amino acid position 100a,  $X_5$  is in position 101 and  $X_6$  is in position 102 of CDRH3 of antibody 4D5. A polypeptide or plurality of polypeptides comprising a variant CDRH3 region in these embodiments can be generated using at least one or more than one of oligonucleotides F171c, F171d, F171e, F171, F185, F186, F187, F185a, F185b, F185b1, F187a, F186a, F187b, and F187c.

In another aspect of the invention, methods and polypeptides, such as antibody variable domains, are provided comprising one, two or all variant CDRs selected from the group consisting of CDRH1, CDRH2 and CDRH3, wherein said variant CDRH3 comprises an amino acid sequence



wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or is tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;

$X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*, *DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine, phenylalanine, glycine, serine, alanine, leucine, or tryptophan;

$X_3$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is alanine, valine, aspartic acid or glycine;

$X_4$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is methionine;

$X_5$  is aspartic acid, alanine, valine, glycine; and

$X_6$  is tyrosine or valine;

and wherein the variant CDRH1 or CDRH2 or both comprise at least one variant amino acid in a solvent accessible and highly diverse amino acid position, wherein the variant amino acid is encoded by a nonrandom codon set, wherein at least about 50%, 60%, 70%, 80%, 90%, or all of the amino acids encoded by the nonrandom  
 5 codon set are target amino for that position in known antibodies or antigen binding fragments (for e.g. antibody variable domains).

In some embodiments of any of the methods and polypeptides described herein, the position in H3 is any of positions 95 to 102 of antibody according to Kabat numbering system (e.g. antibody 4D5). For example, position 95 can have a  
 10 variant amino acid encoded by codon set *DVK, NVT, NNS, XYZ, NNK* or is tryptophan; position 96 can be encoded by *DVK, NVT, NNS, XYZ*, or is glycine or tryptophan; position 97 can be encoded by *DVK, NVT, NNS, XYZ*, or is tryptophan; position 98 can be encoded by *DVK, NVT, NNS, XYZ*, or is tryptophan; position 99 can be encoded by *DVK, NVT, NNS, XYZ*; position 100 can be encoded by *DVK, NVT, NNS, XYZ*, or is tryptophan; position 100a can be encoded by *DVK, DSG, KSG, NVT, NNS, XYZ*, or can be tyrosine, glycine, serine, alanine, tryptophan, aspartic acid, methionine, phenylalanine, leucine, valine; position 100b can be encoded by *DSG, KSG, XYZ* or is alanine, tyrosine, glycine, valine, aspartic acid, methionine, or phenylalanine; Position 100c can be encoded by *KSG, XYZ*, or is  
 20 methionine, phenylalanine, leucine, alanine, glycine, valine, tyrosine, aspartic acid; position 101 can be encoded by *KSG, XYZ* or is aspartic acid, methionine, alanine, valine, glycine, tyrosine, phenylalanine, leucine; and position 102 can be encoded by *KSG or XYZ* or is tyrosine, aspartic acid, methionine, alanine, valine, glycine. A polypeptide or plurality of polypeptides comprising a variant CDRH3 region in  
 25 these embodiments can be generated using at least one or more than one of oligonucleotides illustrated in Figure 4 and Figure 43.

It is contemplated that the sequence diversity of libraries created by introduction of variant amino acids in CDRH3 can be increased by combining these CDRH3 variations with variations in other regions of the antibody, specifically in  
 30 other CDRs of either the light or heavy chain variable sequences. It is contemplated that the nucleic acid sequences that encode members of this set can be further diversified by introduction of other variant amino acids in the CDRs of either the light or heavy chain sequences, via codon sets. Thus, for example, in one embodiment, CDRH3 sequences from fusion polypeptides that bind a target antigen

can be combined with diversified CDRL3, CDRH1, or CDRH2 sequences, or any combination of diversified CDRs.

It should be noted that in some instances framework residues may be varied relative to the sequence of a source antibody or antigen binding fragment, for example, to reflect a consensus sequence or to improve stability or display. For example, framework residues 49, 93, 94 or 71 in the heavy chain may be varied. Heavy chain framework residue 93 may be serine or alanine (which is the human consensus sequence amino acid at that position.) Heavy chain framework residue 94 may be changed to reflect framework consensus sequence from threonine to arginine or lysine. Another example of a framework residue that may be altered is heavy chain framework residue 71, which is R in about 1970 polypeptides, V in about 627 polypeptides and A in about 527 polypeptides, as found in the Kabat database. Heavy chain framework residue 49 may be alanine or glycine. In addition, optionally, the 3 N-terminal amino acids of the heavy chain variable domain can be removed. In the light chain, optionally, the arginine at amino acid position 66 can be changed to glycine.

In one aspect, the invention provides vector constructs for generating fusion polypeptides that bind with significant affinity to potential ligands. These constructs comprise a dimerizable domain that when present in a fusion polypeptide provides for increased tendency for heavy chains to dimerize to form dimers of Fab or Fab' antibody fragments/portions. These dimerization domains may include, eg. a heavy chain hinge sequence that may be present in the fusion polypeptide. Dimerization domains in fusion phage polypeptides bring two sets of fusion polypeptides (LC/HC-phage protein/fragment (such as pIII)) together, thus allowing formation of suitable linkages (such as interheavy chain disulfide bridges) between the two sets of fusion polypeptide. Vector constructs containing such dimerization domains can be used to achieve divalent display of antibody variable domains, for example the diversified fusion proteins described herein, on phage. Preferably, the intrinsic affinity of each monomeric antibody fragment (fusion polypeptide) is not significantly altered by fusion to the dimerization domain. Preferably, dimerization results in divalent phage display which provides increased avidity of phage binding, with significant decrease in off-rate, which can be determined by methods known in the art and as described herein. Dimerization domain-containing vectors of the ..

invention may or may not also include an amber stop codon after the dimerization domain. Illustrative embodiments of vectors are shown in Figure 34.

Dimerization can be varied to achieve different display characteristics.

Dimerization domains can comprise a sequence comprising a cysteine residue, a  
5 hinge region from a full-length antibody, a dimerization sequence such as leucine  
zipper sequence or GCN4 zipper sequence or mixtures thereof. Dimerization  
sequences are known in the art, and include, for example, the GCN4 zipper sequence  
(GRMKQLEDKVEELLSKNYHLENEVARLKKLVGERG) (SEQ ID NO: 3). The  
dimerization domain is preferably located at the C-terminal end of the heavy chain  
10 variable or constant domain sequence and/or between the heavy chain variable or  
constant domain sequence and any viral coat protein component sequence. An  
amber stop codon may also be present at or after the C-terminal end of the  
dimerization domain. In one embodiment, wherein an amber stop codon is present,  
the dimerization domain encodes at least one cysteine and a dimerizing sequence  
15 such as leucine zipper. In another embodiment, wherein no amber stop codon is  
present, then the dimerization domain comprises a single cysteine residue.

The polypeptides of the invention can also be fused to other types of  
polypeptides in order to provide for display of the variant polypeptides or to provide  
for purification, screening or sorting, and detection of the polypeptide. For  
20 embodiment involving phage display, the polypeptides of the invention are fused to  
all or a portion of a viral coat protein. Examples of viral coat protein include protein  
PIII, major coat protein, pVIII, Soc, Hoc, gpD, pVI and variants thereof. In  
addition, the variant polypeptides generated according to the methods of the  
invention can optionally be fused to a polypeptide marker or tag such as FLAG,  
25 polyhistidine, gD, c-myc, B-galactosidase and the like.

### **Methods of Generating Libraries of Randomized Variable Domains**

Methods of substituting an amino acid of choice into a template nucleic acid are well established in the art, some of which are described herein. For example, libraries can be created by targeting solvent accessible and/or highly diverse positions in at least one CDR region for amino acid substitution with variant amino acids using the Kunkel method. See, for e.g., Kunkel et al., Methods Enzymol. (1987), 154:367-382. Generation of randomized sequences is also described below in the Examples.

- 10           The sequence of oligonucleotides includes one or more of the designed codon sets for different lengths of CDRH3 or for the solvent accessible and highly diverse positions in a CDR. A codon set is a set of different nucleotide triplet sequences used to encode desired variant amino acids. Codon sets can be represented using symbols to designate particular nucleotides or equimolar mixtures of nucleotides as shown in below according to the IUB code. Typically, a codon set is represented by three capital letters eg. *NNK*, *NNS*, *DVK* and the like.
- 15

#### **IUB CODES**

G Guanine

A Adenine

20           T Thymine

C Cytosine

R (A or G)

Y (C or T)

M (A or C)

25           K (G or T)

S (C or G)

W (A or T)

H (A or C or T)



B (C or G or T)

V (A or C or G)

D (A or G or T) H

N (A or C or G or T)

5

For example, in the codon set *DVK*, D can be nucleotides A or G or T; V can be A or G or C; and K can be G or T. This codon set can present 18 different codons and can encode amino acids Ala, Trp, Tyr, Lys, Thr, Asn, Lys, Ser, Arg, Asp, Glu, Gly, and Cys.

10 Oligonucleotide or primer sets can be synthesized using standard methods. A set of oligonucleotides can be synthesized, for example, by solid phase synthesis, containing sequences that represent all possible combinations of nucleotide triplets provided by the codon set and that will encode the desired group of amino acids. Synthesis of oligonucleotides with selected nucleotide "degeneracy" at certain  
15 positions is well known in that art. Such sets of nucleotides having certain codon sets can be synthesized using commercial nucleic acid synthesizers (available from, for example, Applied Biosystems, Foster City, CA), or can be obtained commercially (for example, from Life Technologies, Rockville, MD). Therefore, a set of oligonucleotides synthesized having a particular codon set will typically  
20 include a plurality of oligonucleotides with different sequences, the differences established by the codon set within the overall sequence. Oligonucleotides, as used according to the invention, have sequences that allow for hybridization to a variable domain nucleic acid template and also can include restriction enzyme sites for cloning purposes.

25 In one method, nucleic acid sequences encoding variant amino acids can be created by oligonucleotide-mediated mutagenesis of a nucleic acid sequence encoding a source or template polypeptide such as the antibody variable domain of 4D5. This technique is well known in the art as described by Zoller et al. Nucleic Acids Res. 10:6487-6504(1987). Briefly, nucleic acid sequences encoding variant  
30 amino acids are created by hybridizing an oligonucleotide set encoding the desired codon sets to a DNA template, where the template is the single-stranded form of the plasmid containing a variable region nucleic acid template sequence. After

hybridization, DNA polymerase is used to synthesize an entire second complementary strand of the template that will thus incorporate the oligonucleotide primer, and will contain the codon sets as provided by the oligonucleotide set.

Nucleic acids encoding other source or template molecules are known or can be readily determined.

Generally, oligonucleotides of at least 25 nucleotides in length are used. An optimal oligonucleotide will have 12 to 15 nucleotides that are completely complementary to the template on either side of the nucleotide(s) coding for the mutation(s). This ensures that the oligonucleotide will hybridize properly to the single-stranded DNA template molecule. The oligonucleotides are readily synthesized using techniques known in the art such as that described by Crea et al., *Proc. Nat'l. Acad. Sci. USA*, 75:5765 (1978).

The DNA template is generated by those vectors that are either derived from bacteriophage M13 vectors (the commercially available M13mp18 and M13mp19 vectors are suitable), or those vectors that contain a single-stranded phage origin of replication as described by Viera et al., *Meth. Enzymol.*, 153:3 (1987). Thus, the DNA that is to be mutated can be inserted into one of these vectors in order to generate single-stranded template. Production of the single-stranded template is described in sections 4.21-4.41 of Sambrook et al., above.

To alter the native DNA sequence, the oligonucleotide is hybridized to the single stranded template under suitable hybridization conditions. A DNA polymerizing enzyme, usually T7 DNA polymerase or the Klenow fragment of DNA polymerase I, is then added to synthesize the complementary strand of the template using the oligonucleotide as a primer for synthesis. A heteroduplex molecule is thus formed such that one strand of DNA encodes the mutated form of gene 1, and the other strand (the original template) encodes the native, unaltered sequence of gene 1. This heteroduplex molecule is then transformed into a suitable host cell, usually a prokaryote such as *E. coli* JM101. After growing the cells, they are plated onto agarose plates and screened using the oligonucleotide primer radiolabelled with a 32-Phosphate to identify the bacterial colonies that contain the mutated DNA.

The method described immediately above may be modified such that a homoduplex molecule is created wherein both strands of the plasmid contain the mutation(s). The modifications are as follows: The single stranded oligonucleotide

is annealed to the single-stranded template as described above. A mixture of three deoxyribonucleotides, deoxyriboadenosine (dATP), deoxyriboguanosine (dGTP), and deoxyribothymidine (dTTP), is combined with a modified thiodeoxyribocytosine called dCTP-(aS) (which can be obtained from Amersham). This mixture is added  
5 to the template-oligonucleotide complex. Upon addition of DNA polymerase to this mixture, a strand of DNA identical to the template except for the mutated bases is generated. In addition, this new strand of DNA will contain dCTP-(aS) instead of dCTP, which serves to protect it from restriction endonuclease digestion. After the template strand of the double-stranded heteroduplex is nicked with an appropriate  
10 restriction enzyme, the template strand can be digested with ExoIII nuclease or another appropriate nuclease past the region that contains the site(s) to be mutagenized. The reaction is then stopped to leave a molecule that is only partially single-stranded. A complete double-stranded DNA homoduplex is then formed using DNA polymerase in the presence of all four deoxyribonucleotide  
15 triphosphates, ATP, and DNA ligase. This homoduplex molecule can then be transformed into a suitable host cell.

As indicated previously the sequence of the oligonucleotide set is of sufficient length to hybridize to the template nucleic acid and may also, but does not necessarily, contain restriction sites. The DNA template can be generated by those  
20 vectors that are either derived from bacteriophage M13 vectors or vectors that contain a single-stranded phage origin of replication as described by Viera et al. ((1987) Meth. Enzymol., 153:3). Thus, the DNA that is to be mutated must be inserted into one of these vectors in order to generate single-stranded template. Production of the single-stranded template is described in sections 4.21-4.41 of  
25 Sambrook et al., supra.

According to another method, a library can be generated by providing upstream and downstream oligonucleotide sets, each set having a plurality of oligonucleotides with different sequences, the different sequences established by the codon sets provided within the sequence of the oligonucleotides. The upstream and  
30 downstream oligonucleotide sets, along with a variable domain template nucleic acid sequence, can be used in a polymerase chain reaction to generate a "library" of PCR products. The PCR products can be referred to as "nucleic acid cassettes", as they can be fused with other-related or unrelated nucleic acid sequences, for example,

viral coat protein components and dimerization domains, using established molecular biology techniques.

The sequence of the PCR primers includes one or more of the designed codon sets for the solvent accessible and highly diverse positions in a CDR region.

5 As described above, a codon set is a set of different nucleotide triplet sequences used to encode desired variant amino acids.

Oligonucleotide sets can be used in a polymerase chain reaction using a variable region nucleic acid template sequence as the template to create nucleic acid cassettes. The variable region nucleic acid template sequence can be any portion of  
10 the light or heavy immunoglobulin chains containing the target nucleic acid sequences (ie., nucleic acid sequences encoding amino acids targeted for substitution). The variable region nucleic acid template sequence is a portion of a double stranded DNA molecule having a first nucleic acid strand and complementary second nucleic acid strand. The variable region nucleic acid  
15 template sequence contains at least a portion of a variable domain and has at least one CDR. In some cases, the variable region nucleic acid template sequence contains more than one CDR. An upstream portion and a downstream portion of the variable region nucleic acid template sequence can be targeted for hybridization with members of an upstream oligonucleotide set and a downstream oligonucleotide  
20 set.

A first oligonucleotide of the upstream primer set can hybridize to the first nucleic acid strand and a second oligonucleotide of the downstream primer set can hybridize to the second nucleic acid strand. The oligonucleotide primers can include one or more codon sets and be designed to hybridize to a portion of the variable  
25 region nucleic acid template sequence. Use of these oligonucleotides can introduce two or more codon sets into the PCR product (ie., the nucleic acid cassette) following PCR. The oligonucleotide primer that hybridizes to regions of the nucleic acid sequence encoding the antibody variable domain includes portions that encode CDR residues that are targeted for amino acid substitution.

30 The upstream and downstream oligonucleotide sets can also be synthesized to include restriction sites within the oligonucleotide sequence. These restriction sites can facilitate the insertion of the nucleic acid cassettes [ie., PCR reaction products] into an expression vector having additional antibody sequences. Preferably, the restriction sites are designed to facilitate the cloning of the nucleic

acid cassettes without introducing extraneous nucleic acid sequences or removing original CDR or framework nucleic acid sequences.

Nucleic acid cassettes can be cloned into any suitable vector for expression of a portion or the entire light or heavy chain sequence containing the targeted amino acid substitutions generated. According to methods detailed in the invention, the nucleic acid cassette is cloned into a vector allowing production of a portion or the entire light or heavy chain sequence fused to all or a portion of a viral coat protein (ie., creating a fusion protein) and displayed on the surface of a particle or cell. While several types of vectors are available and may be used to practice this invention, phagemid vectors are the preferred vectors for use herein, as they may be constructed with relative ease, and can be readily amplified. Phagemid vectors generally contain a variety of components including promoters, signal sequences, phenotypic selection genes, origin of replication sites, and other necessary components as are known to those of ordinary skill in the art.

In another embodiment, wherein a particular variant amino acid combination is to be expressed, the nucleic acid cassette contains a sequence that is able to encode all or a portion of the heavy or light chain variable domain, and is able to encode the variant amino acid combinations. For production of antibodies containing these variant amino acids or combinations of variant amino acids, as in a library, the nucleic acid cassettes can be inserted into an expression vector containing additional antibody sequence, for example all or portions of the variable or constant domains of the light and heavy chain variable regions. These additional antibody sequences can also be fused to other nucleic acids sequences, such as sequences which encode viral coat protein components and therefore allow production of a fusion protein.

### Vectors

One aspect of the invention includes a replicable expression vector comprising a nucleic acid sequence encoding a gene fusion, wherein the gene fusion encodes a fusion protein comprising an antibody variable domain, or an antibody variable domain and a constant domain, fused to all or a portion of a viral coat protein. Also included is a library of diverse replicable expression vectors comprising a plurality of gene fusions encoding a plurality of different fusion proteins including a plurality of the antibody variable domains generated with diverse sequences as described above. The vectors can include a variety of

components and are preferably constructed to allow for movement of antibody variable domain between different vectors and /or to provide for display of the fusion proteins in different formats.

Examples of vectors include phage vectors. The phage vector has a phage  
5 origin of replication allowing phage replication and phage particle formation. The phage is preferably a filamentous bacteriophage, such as an M13, f1, fd, Pf3 phage or a derivative thereof, or a lambdoid phage, such as lambda, 21, phi80, phi81, 82, 424, 434, etc., or a derivative thereof.

Examples of viral coat proteins include infectivity protein PIII, major coat  
10 protein PVIII, p3, Soc (T4), Hoc (T4), gpD (of bacteriophage lambda), minor bacteriophage coat protein 6 (pVI) (filamentous phage; J Immunol Methods. 1999 Dec 10;231(1-2):39-51), variants of the M13 bacteriophage major coat protein (P8) (Protein Sci 2000 Apr;9(4):647-54). The fusion protein can be displayed on the surface of a phage and suitable phage systems include M13KO7 helper phage,  
15 M13R408, M13-VCS, and Phi X 174, pJuFo phage system (J Virol. 2001 Aug;75(15):7107-13.v), hyperphage (Nat Biotechnol. 2001 Jan;19(1):75-8). The preferred helper phage is M13KO7, and the preferred coat protein is the M13 Phage gene III coat protein. The preferred host is *E. coli*, and protease deficient strains of *E. coli*. Vectors, such as the fth1 vector (Nucleic Acids Res. 2001 May  
20 15;29(10):E50-0) can be useful for the expression of the fusion protein.

The expression vector also can have a secretory signal sequence fused to the DNA encoding each subunit of the antibody or fragment thereof. This sequence is typically located immediately 5' to the gene encoding the fusion protein, and will thus be transcribed at the amino terminus of the fusion protein. However, in certain  
25 cases, the signal sequence has been demonstrated to be located at positions other than 5' to the gene encoding the protein to be secreted. This sequence targets the protein to which it is attached across the inner membrane of the bacterial cell. The DNA encoding the signal sequence may be obtained as a restriction endonuclease fragment from any gene encoding a protein that has a signal sequence. Suitable  
30 prokaryotic signal sequences may be obtained from genes encoding, for example, LamB or OmpF (Wong et al., Gene, 68:1931 (1983), MalE, PhoA and other genes. A preferred prokaryotic signal sequence for practicing this invention is the *E. coli* heat-stable enterotoxin II (STII) signal sequence as described by Chang et al., Gene 55:189 (1987), and malE.

The vector also typically includes a promoter to drive expression of the fusion protein. Promoters most commonly used in prokaryotic vectors include the lac Z promoter system, the alkaline phosphatase pho A promoter (Ap), the bacteriophage  $\lambda_{PL}$  promoter (a temperature sensitive promoter), the tac promoter (a  
5 hybrid trp-lac promoter that is regulated by the lac repressor), the tryptophan promoter, and the bacteriophage T7 promoter. For general descriptions of promoters, see section 17 of Sambrook et al. supra. While these are the most commonly used promoters, other suitable microbial promoters may be used as well.

The vector can also include other nucleic acid sequences, for example,  
10 sequences encoding gD tags, c-Myc epitopes, poly-histidine tags, fluorescence proteins (eg., GFP), or beta-galactosidase protein which can be useful for detection or purification of the fusion protein expressed on the surface of the phage or cell. Nucleic acid sequences encoding, for example, a gD tag, also provide for positive or negative selection of cells or virus expressing the fusion protein. In some  
15 embodiments, the gD tag is preferably fused to an antibody variable domain which is not fused to the viral coat protein component. Nucleic acid sequences encoding, for example, a polyhistidine tag, are useful for identifying fusion proteins including antibody variable domains that bind to a specific antigen using immunohistochemistry. Tags useful for detection of antigen binding can be fused to  
20 either an antibody variable domain not fused to a viral coat protein component or an antibody variable domain fused to a viral coat protein component.

Another useful component of the vectors used to practice this invention is phenotypic selection genes. Typical phenotypic selection genes are those encoding proteins that confer antibiotic resistance upon the host cell. By way of illustration,  
25 the ampicillin resistance gene (*amp<sup>r</sup>*), and the tetracycline resistance gene (*tetr*) are readily employed for this purpose.

The vector can also include nucleic acid sequences containing unique restriction sites and suppressible stop codons. The unique restriction sites are useful for moving antibody variable domains between different vectors and expression  
30 systems, especially useful for production of full-length antibodies or antigen binding fragments in cell cultures. The suppressible stop codons are useful to control the level of expression of the fusion protein and to facilitate purification of soluble antibody fragments. For example, an amber stop codon can be read as Gln in a *supE*

host to enable phage display, while in a non-*supE* host it is read as a stop codon to produce soluble antibody fragments without fusion to phage coat proteins. These synthetic sequences can be fused to one or more antibody variable domains in the vector.

5           It is preferable to use vector systems that allow the nucleic acid encoding an antibody sequence of interest, for example a CDR having variant amino acids, to be easily removed from the vector system and placed into another vector system. For example, appropriate restriction sites can be engineered in a vector system to facilitate the removal of the nucleic acid sequence encoding an antibody or antibody  
10       variable domain having variant amino acids. The restriction sequences are usually chosen to be unique in the vectors to facilitate efficient excision and ligation into new vectors. Antibodies or antibody variable domains can then be expressed from vectors without extraneous fusion sequences, such as viral coat proteins or other sequence tags.

15           Between nucleic acid encoding antibody variable or constant domain (gene 1) and the viral coat protein component (gene 2), DNA encoding a termination or stop codon may be inserted, such termination codons including UAG (amber), UAA (ocher) and UGA (opal). (*Microbiology*, Davis et al., Harper & Row, New York, 1980, pp. 237, 245-47 and 374). The termination or stop codon expressed in a wild  
20       type host cell results in the synthesis of the gene 1 protein product without the gene 2 protein attached. However, growth in a suppressor host cell results in the synthesis of detectable quantities of fused protein. Such suppressor host cells are well known and described, such as *E. coli* suppressor strain (Bullock et al., *BioTechniques* 5:376-379 (1987)). Any acceptable method may be used to place  
25       such a termination codon into the mRNA encoding the fusion polypeptide.

          The suppressible codon may be inserted between the first gene encoding a antibody variable or constant domain, and a second gene encoding at least a portion of a phage coat protein. Alternatively, the suppressible termination codon may be inserted adjacent to the fusion site by replacing the last amino acid triplet in the  
30       antibody variable domain or the first amino acid in the phage coat protein. The suppressible termination codon may be located at or after the C-terminal end of a dimerization domain. When the plasmid containing the suppressible codon is grown in a suppressor host cell, it results in the detectable production of a fusion polypeptide containing the polypeptide and the coat protein. When the plasmid is



grown in a non-suppressor host cell, the antibody variable domain is synthesized substantially without fusion to the phage coat protein due to termination at the inserted suppressible triplet UAG, UAA, or UGA. In the non-suppressor cell the antibody variable domain is synthesized and secreted from the host cell due to the  
5 absence of the fused phage coat protein which otherwise anchored it to the host membrane.

In some embodiments, the CDR being diversified (randomized) may have a stop codon engineered in the template sequence (referred to herein as a “stop template”). This feature provides for detection and selection of successfully  
10 diversified sequences based on successful repair of the stop codon(s) in the template sequence due to incorporation of the oligonucleotide(s) comprising the sequence(s) for the variant amino acids of interest. This feature is further illustrated in the Examples below.

The light and/or heavy chain antibody variable or constant domains can also  
15 be fused to an additional peptide sequence, the additional peptide sequence providing for the interaction of one or more fusion polypeptides on the surface of the viral particle or cell. These peptide sequences are herein referred to as “dimerization domains”. Dimerization domains may comprise at least one or more of a dimerization sequence, or at least one sequence comprising a cysteine residue or  
20 both. Suitable dimerization sequences include those of proteins having amphipathic alpha helices in which hydrophobic residues are regularly spaced and allow the formation of a dimer by interaction of the hydrophobic residues of each protein; such proteins and portions of proteins include, for example, leucine zipper regions. Dimerization domains can also comprise one or more cysteine residues (e.g. as  
25 provided by inclusion of an antibody hinge sequence within the dimerization domain). The cysteine residues can provide for dimerization by formation of one or more disulfide bonds. In one embodiment, wherein a stop codon is present after the dimerization domain, the dimerization domain comprises at least one cysteine residue. The dimerization domains are preferably located between the antibody  
30 variable or constant domain and the viral coat protein component.

In some cases the vector encodes a single antibody-phage polypeptide in a single chain form containing, for example, both the heavy and light chain variable regions fused to a coat protein. In these cases the vector is considered to be “monocistronic”, expressing one transcript under the control of a certain promoter.

Illustrative examples of such vectors are shown in Figures 34C and D. In Figure 34C, a vector is shown as utilizing the alkaline phosphatase (AP) or Tac promoter to drive expression of a monocistronic sequence encoding VL and VH domains, with a linker peptide between the VL and VH domains. This cistronic sequence is  
5 connected at the 5' end to an *E. coli male* or heat-stable enterotoxin II (STII) signal sequence and at its 3' end to all or a portion of a viral coat protein (shown in the Figure 34 as the pIII protein). The fusion polypeptide encoded by this vector is referred to herein as "ScFv-pIII". In some embodiments, illustrated in Figure 34D, the vector may further comprise a sequence encoding a dimerization domain (such  
10 as a leucine zipper) at its 3' end, between the second variable domain sequence (VH in Figure 34D) and the viral coat protein sequence. Fusion polypeptides comprising the dimerization domain are capable of dimerizing to form a complex of two scFv polypeptides (referred to herein as "(ScFv)<sub>2</sub>-pIII").

In other cases, the variable regions of the heavy and light chains can be  
15 expressed as separate polypeptides, the vector thus being "bicistronic", allowing the expression of separate transcripts. Examples of bicistronic vectors are schematically shown in Figures 34A and 4B. In these vectors, a suitable promoter, such as the Ptac or PhoA promoter, can be used to drive expression of a bicistronic message. A first cistron, encoding, for example, a light chain variable and constant domain, is  
20 connected at the 5' end to a *E. coli male* or heat-stable enterotoxin II (STII) signal sequence and at the 3' end to a nucleic acid sequence encoding a gD tag. A second cistron, encoding, for example, a heavy chain variable domain and constant domain CH1, is connected at its 5' end to a *E. coli male* or heat-stable enterotoxin II (STII) signal sequence and at the 3' end to all or a portion of a viral coat protein.

25 A vector which provides a bicistronic message and for display of F(ab')<sub>2</sub>-pIII is shown in Figure 34B. In this vector, a suitable promoter, such as Ptac or PhoA (AP) promoter drives expression of first cistron encoding a light chain variable and constant domain operably linked at 5' end to a *E. coli male* or heat stable enterotoxin II (STII) signal sequence and at the 3' end to a nucleic acid sequence  
30 encoding a gD tag. The second cistron encodes, for example, a heavy chain variable and constant domain operatively linked at 5' end to a *E. coli male* or heat stable enterotoxin II (STII) signal sequence and at 3' end has a dimerization domain comprising IgG hinge sequence and a leucine zipper sequence followed by at least a portion of viral coat protein.

### **Display of Fusion Polypeptides**

Fusion polypeptides of an antibody variable domain can be displayed on the surface of a cell, virus, or phagemid particle in a variety of formats. These formats include single chain Fv fragment (scFv), F(ab) fragment and multivalent forms of these fragments. The multivalent forms preferably are a dimer of ScFv, Fab, or F(ab'), herein referred to as (ScFv)<sub>2</sub>, F(ab)<sub>2</sub> and F(ab')<sub>2</sub>, respectively. The multivalent forms of display are preferred in part because they have more than one antigen binding site which generally results in the identification of lower affinity clones and also allows for more efficient sorting of rare clones during the selection process.

Methods for displaying fusion polypeptides comprising antibody fragments, on the surface of bacteriophage, are well known in the art, for example as described in patent publication number WO 92/01047 and herein. Other patent publications WO 92/20791; WO 93/06213; WO 93/11236 and WO 93/19172, describe related methods and are all herein incorporated by reference. Other publications have shown the identification of antibodies with artificially rearranged V gene repertoires against a variety of antigens displayed on the surface of phage (for example, H. R. Hoogenboom & G. Winter J. Mol. Biol. 227 381-388 1992; and as disclosed in WO 93/06213 and WO 93/11236).

When a vector is constructed for display in a scFv format, it includes nucleic acid sequences encoding an antibody variable light chain domain and an antibody variable heavy chain variable domain. Typically, the nucleic acid sequence encoding an antibody variable heavy chain domain is fused to a viral coat protein component. One or both of the antibody variable domains can have variant amino acids in at least one CDR region. The nucleic acid sequence encoding the antibody variable light chain is connected to the antibody variable heavy chain domain by a nucleic acid sequence encoding a peptide linker. The peptide linker typically contains about 5 to 15 amino acids. Optionally, other sequences encoding, for example, tags useful for purification or detection can be fused at the 3' end of either the nucleic acid sequence encoding the antibody variable light chain or antibody variable heavy chain domain or both.

When a vector is constructed for F(ab) display, it includes nucleic acid sequences encoding antibody variable domains and antibody constant domains. A nucleic acid encoding a variable light chain domain is fused to a nucleic acid

sequence encoding a light chain constant domain. A nucleic acid sequence encoding an antibody heavy chain variable domain is fused to a nucleic acid sequence encoding a heavy chain constant CH1 domain. Typically, the nucleic acid sequence encoding the heavy chain variable and constant domains are fused to a nucleic acid sequence encoding all or part of a viral coat protein. One or both of the antibody variable light or heavy chain domains can have variant amino acids in at least one CDR. The heavy chain variable and constant domains are preferably expressed as a fusion with at least a portion of a viral coat protein and the light chain variable and constant domains are expressed separately from the heavy chain viral coat fusion protein. The heavy and light chains associate with one another, which may be by covalent or non-covalent bonds. Optionally, other sequences encoding, for example, polypeptide tags useful for purification or detection, can be fused at the 3' end of either the nucleic acid sequence encoding the antibody light chain constant domain or antibody heavy chain constant domain or both.

Preferably a bivalent moiety, for example, a  $F(ab)_2$  dimer or  $F(ab')_2$  dimer, is used for displaying antibody fragments with the variant amino acid substitutions on the surface of a particle. It has been found that  $F(ab')_2$  dimers have the same affinity as  $F(ab)$  dimers in a solution phase antigen binding assay but the off rate for  $F(ab')_2$  are reduced because of a higher avidity. Therefore the bivalent format (for example,  $F(ab')_2$ ) is a particularly useful format since it can allow for the identification of lower affinity clones and also allows more efficient sorting of rare clones during the selection process.

#### Introduction of Vectors into Host Cells

Vectors constructed as described in accordance with the invention are introduced into a host cell for amplification and/or expression. Vectors can be introduced into host cells using standard transformation methods including electroporation, calcium phosphate precipitation and the like. If the vector is an infectious particle such as a virus, the vector itself provides for entry into the host cell. Transfection of host cells containing a replicable expression vector which encodes the gene fusion and production of phage particles according to standard procedures provides phage particles in which the fusion protein is displayed on the surface of the phage particle.

Replicable expression vectors are introduced into host cells using a variety of methods. In one embodiment, vectors can be introduced into cells using

electroporation as described in WO/00106717. Cells are grown in culture in standard culture broth, optionally for about 6-48 hours (or to  $OD_{600} = 0.6 - 0.8$ ) at about 37°C, and then the broth is centrifuged and the supernatant removed (e.g. decanted). Initial purification is preferably by resuspending the cell pellet in a buffer solution (e.g. 1.0 mM HEPES pH 7.4) followed by recentrifugation and removal of supernatant. The resulting cell pellet is resuspended in dilute glycerol (e.g. 5-20% v/v) and again recentrifuged to form a cell pellet and the supernatant removed. The final cell concentration is obtained by resuspending the cell pellet in water or dilute glycerol to the desired concentration.

10 A particularly preferred recipient cell is the electroporation competent *E. coli* strain of the present invention, which is *E. coli* strain SS320 (Sidhu et al., *Methods Enzymol.* (2000), 328:333-363). Strain SS320 was prepared by mating MC1061 cells with XL1-BLUE cells under conditions sufficient to transfer the fertility episome (F' plasmid) or XL1-BLUE into the MC1061 cells. Strain SS320 has been deposited with the American Type Culture Collection (ATCC), 10801 University Boulevard, Manassas, Virginia USA, on June 18, 1998 and assigned Deposit Accession No. 98795. Any F' episome which enables phage replication in the strain may be used in the invention. Suitable episomes are available from strains deposited with ATCC or are commercially available (CJ236, CSH18, DHF', JM101, JM103, JM105, JM107, JM109, JM110), KS1000, XL1-BLUE, 71-18 and others).

20 The use of higher DNA concentrations during electroporation (about 10X) increases the transformation efficiency and increases the amount of DNA transformed into the host cells. The use of high cell concentrations also increases the efficiency (about 10X). The larger amount of transferred DNA produces larger libraries having greater diversity and representing a greater number of unique members of a combinatorial library. Transformed cells are generally selected by growth on antibiotic containing medium.

#### **Selection (sorting) and Screening for Binders to targets of choice**

30 Use of phage display for identifying target antigen binders, with its various permutations and variations in methodology, are well established in the art. One approach involves constructing a family of variant replicable vectors containing a transcription regulatory element operably linked to a gene fusion encoding a fusion polypeptide; transforming suitable host cells, culturing the transformed cells to form phage particles which display the fusion polypeptide on the surface of the phage

particle, followed by a process that entails selection or sorting by contacting the recombinant phage particles with a target antigen so that at least a portion of the population of particles bind to the target with the objective to increase and enrich the subsets of the particles which bind from particles relative to particles that do not bind in the process of selection. The selected pool can be amplified by infecting host cells, such as fresh XL1-Blue cells, for another round of sorting on the same target with different or same stringency. The resulting pool of variants are then screened against the target antigens to identify novel high affinity binding proteins. These novel high affinity binding proteins can be useful as therapeutic agents as antagonists or agonists, and/or as diagnostic and research reagents.

Fusion polypeptides such as antibody variable domains comprising the variant amino acids can be expressed on the surface of a phage, phagemid particle or a cell and then selected and/or screened for the ability of members of the group of fusion polypeptides to bind a target antigen which is typically an antigen of interest. The processes of selection for binders to target can also include sorting on a generic protein having affinity for antibody variable domains such as protein L or a tag specific antibody which binds to antibody or antibody fragments displayed on phage, which can be used to enrich for library members that display correctly folded antibody fragments (fusion polypeptides).

Target proteins, such as receptors, may be isolated from natural sources or prepared by recombinant methods by procedures known in the art. Target antigens can include a number of molecules of therapeutic interest.

Two main strategies of selection (sorting) for affinity can be used as depicted schematically in Figure 45. The first strategy (left of Figure) is solid-support method or plate sorting or immobilized target sorting. The second strategy is a solution-binding method (right).

For the solid support method, the target protein may be attached to a suitable solid or semi solid matrix which are known in the art such as agarose beads, acrylamide beads, glass beads, cellulose, various acrylic copolymers, hydroxyalkyl methacrylate gels, polyacrylic and polymethacrylic copolymers, nylon, neutral and ionic carriers, and the like. Attachment of the target protein to the matrix may be accomplished by methods described in *Methods in Enzymology*, 44 (1976), or by other means known in the art.

After attachment of the target antigen to the matrix, the immobilized target is contacted with the library expressing the fusion polypeptides under conditions suitable for binding of at least a subset of the phage particle population with the immobilized target antigen. Normally, the conditions, including pH, ionic strength, temperature and the like will mimic physiological conditions. Bound particles ("binders") to the immobilized target are separated from those particles that do not bind to the target by washing. Wash conditions can be adjusted to result in removal of all but the high affinity binders. Binders may be dissociated from the immobilized target by a variety of methods. These methods include competitive dissociation using the wild-type ligand (e.g. excess target antigen), altering pH and/or ionic strength, and methods known in the art. Selection of binders typically involves elution from an affinity matrix with a suitable elution material such as acid like 0.1M HCl or ligand. Elution with increasing concentrations of ligand could elute displayed binding molecules of increasing affinity.

The binders can be isolated and then re-amplified in suitable host cells by infecting the cells with the viral particles that are binders (and helper phage if necessary, e.g. when viral particle is a phagemid particle) and the host cells are cultured under conditions suitable for amplification of the particles that display the desired fusion polypeptide. The phage particles are then collected and the selection process is repeated one or more times until binders of the target antigen are enriched in a way. Any number of rounds of selection or sorting can be utilized. One of the selection or sorting procedures can involve isolating binders that bind to a generic affinity protein such as protein L or an antibody to a polypeptide tag present in a displayed polypeptide such as antibody to the gD protein or polyhistidine tag.

One aspect of the invention involves a novel selection method which is termed "solution-binding method" as schematized in Figure 45 (right panel). The invention allows solution phase sorting with much improved efficiency over the conventional solution sorting method. The solution binding method has been used for finding original binders from a random library or finding improved binders from a library that was designated to improve affinity of a particular binding clone or group of clones. The method comprises contacting a plurality of polypeptides, such as those displayed on phage or phagemid particles (library), with a target antigen labelled or fused with a tag molecule. The tag could be biotin or other moieties for which specific binders are available. The stringency of the solution phase can be

varied by using decreasing concentrations of labelled target antigen in the first solution binding phase. To further increase the stringency, the first solution binding phase can be followed by a second solution phase having high concentration of unlabelled target antigen after the initial binding with the labelled target in the first solution phase. Usually, 100 to 1000 fold of unlabelled target over labelled target is used in the second phase (if included). The length of time of incubation of the first solution phase can vary from a few minutes to one to two hours or longer to reach equilibrium. Using a shorter time for binding in this first phase may bias or select for binders that have fast on-rate. The length of time and temperature of incubation in second phase can be varied to increase the stringency. This provides for a selection bias for binders that have slow rate of coming off the target (off-rate). After contacting the plurality of polypeptides (displayed on the phage/ phagemid particles) with a target antigen, the phage or phagemid particles that are bound to labelled targets are separated from phage that do not bind. The particle-target mixture from solution phase of binding is isolated by contacting it with the labelled target moiety and allowing for its binding to, a molecule that binds the labelled target moiety for a short period of time (eg. 2-5 minutes). The initial concentration of the labelled target antigen can range from about 0.1 nM to about 1000nM. The bound particles are eluted and can be propagated for next round of sorting. Multiple rounds of sorting are preferred using a lower concentration of labelled target antigen with each round of sorting.

For example, an initial sort or selection using about 100 to 250 nM labelled target antigen should be sufficient to capture a wide range of affinities, although this factor can be determined empirically and/or to suit the desire of the practitioner. In the second round of selection, about 25 to 100 nM of labelled target antigen may be used. In the third round of selection, about 0.1 to 25 nM of labled target antigen may be used. For example, to improve the affinity of a 100 nM binder, it may be desirable to start with 20 nM and then progress to 5 and 1 nM labelled target, then, followed by even lower concentrations such as about 0.1 nM labelled target antigen.

The conventional solution sorting involves use of beads like strepavidin coated beads, which is very cumbersome to use and often results in very low efficiency of phage binders recovery. The conventional solution sorting with beads takes much longer than 2-5 minutes and is less feasible to adapt to high throughput automation than the invention described above.



As described herein, combinations of solid support and solution sorting methods can be advantageously used to isolate binders having desired characteristics. After selection/sorting on target antigen for a few rounds, screening of individual clones from the selected pool generally is performed to identify  
5 specific binders with the desired properties/ characteristics. Preferably, the process of screening is carried out by automated systems to allow for high-throughput screening of library candidates.

Two major screening methods are described below. However, other methods known in the art may also be used in the methods of the invention. The first  
10 screening method comprises a phage ELISA assay with immobilized target antigen, which provides for identification of a specific binding clone from a non-binding clone. Specificity can be determined by simultaneous assay of the clone on target coated well and BSA or other non-target protein coated wells. This assay is automatable for high throughput screening.

15 One embodiment provides a method of selecting for an antibody variable domain that binds to a specific target antigen from a library of antibody variable domain by generating a library of replicable expression vectors comprising a plurality of polypeptides ; contacting the library with a target antigen and at least one nontarget antigen under conditions suitable for binding; separating the  
20 polypeptide binders in the library from the nonbinders; identifying the binders that bind to the target antigen and do not bind to the nontarget antigen; eluting the binders from the target antigen; and amplifying the replicable expression vectors comprising the polypeptide binder that bind to a specific antigen.

The second screening assay is an invention embodied in this application  
25 which is a affinity screening assay that provides for screening for clones that have high affinity from clones that have low affinity in a high throughput manner. In the assay, each clone is assayed with and without first incubating with target antigen of certain concentration for a period of time (for e.g 30-60 minutes) before application to target coated wells briefly (e.g. 5-15 minutes). Then bound phage is measured by  
30 usual phage ELISA method, eg. using anti-M13 HRP conjugates. The ratio of binding signal of the two wells, one well having been preincubated with target and the other well not preincubated with target antigen is an indication of affinity. The selection of the concentraion of target for first incubation depends on the affinity range of interest. For example, if binders with affinity higher than 10nM are

desired, 100nM of target in the first incubation is often used. See Figure 47 and example 9 for detailed description of one embodiment of the method. Once binders are found from a particular round of sorting (selection), these clones can be screened with affinity screening assay to identify binders with higher affinity.

5           Combinations of any of the sorting/ selection methods described above may be combined with the screening methods. For example, in one embodiment, polypeptide binders are first selected for binding to immobilized target antigen. Polypeptide binders that bind to the immobilized target antigen can then be amplified and screened for binding to the target antigen and for lack of binding to  
10   nontarget antigens. Polypeptide binders that bind specifically to the target antigen are amplified. These polypeptide binders can then selected for higher affinity by contact with a concentration of a labelled target antigen to form a complex, wherein the concentration ranges of labelled target antigen from about 0.1 nM to about 1000  
15   nM, the complexes are isolated by contact with an agent that binds to the label on the target antigen. The polypeptide binders are then eluted from the labeled target antigen and optionally, the rounds of selection are repeated, each time a lower concentration of labelled target antigen is used. The high affinity polypeptide  
20   binders isolated using this selection method can then be screened for high affinity using for example, the solution phase ELISA assay as described in Example 8 or the spot competition ELISA assay as described in Example 9.

          These methods can provide for finding clones with high affinity without having to perform long and complex competition affinity assays on a large number of clones. The intensive aspect of doing complex assays of many clones often is a significant obstacle to finding best clones from a selection. This method is  
25   especially useful in affinity improvement efforts where multiple binders with similar affinity can be recovered from the selection process. Different clones may have very different efficiency of expression/display on phage or phagemid particles. Those clones more highly expressed have better chances being recovered. That is, the selection can be biased by the display or expression level of the variants. The  
30   solution-binding sorting method of the invention can improve the selection process for finding binders with high affinity. This method is an affinity screening assay that provides a significant advantage in screening for the best binders quickly and easily.

After binders are identified by binding to the target antigen, the nucleic acid can be extracted. Extracted DNA can then be used directly to transform *E. coli* host cells or alternatively, the encoding sequences can be amplified, for example using PCR with suitable primers, and sequenced by typical sequencing method. Variable domain DNA of the binders can be restriction enzyme digested and then inserted into a vector for protein expression.

In one embodiment, the invention provides isolation of novel antibody and antibody fragments that bind to mVEGF (murine Vascular Endothelial Growth Factor). Preferably, the antibody variable domains bind mVEGF with an  $IC_{50}$  of less than 10  $\mu$ M and more preferably less than 1  $\mu$ M. In one embodiment, mVEGF-binding antibodies include members of the library created by substituting amino acid in residues in CDR-L3 and residues 95-100a of the CDRH3 region of the variable region of the heavy chain with *DVK* codon sets or a combination of *DVK* and *NNK* codon sets. It has been discovered that some members of the library, as created above, have a particularly high affinity for mVEGF.

In particular, antibodies including the heavy chain CDR3 sequences SRNAWAF (SEQ ID NO: 5; amino acid position 93-100c), SRNLSSENSYAM (SEQ ID NO: 6; amino acid position 93-100c), SRAGWAGWYAM (SEQ ID NO: 7; amino acid position 93-100c), SRAAKAGWYAM (SEQ ID NO: 8; amino acid position 93-100c), and SRSDGRDSAYAM (SEQ ID NO: 9; amino acid position 93-100c) display high affinity binding to mVEGF. Novel antibody variable domains that bind to mVEGF, generated by substituting amino acids at positions in other CDRs, such as L1, L2, L3, H1 and H2 can also be generated according to the method described herein.

In some cases, novel CDRH1/H2/H3 binders for example, sequences can be combined with other sequences generated by introducing variant amino acids via codon sets into the other light chains CDRs, for example through a 2-step process. An example of a 2-step process comprises first determining binders (generally lower affinity binders) within one or more libraries generated by randomizing one or more CDRs, wherein the CDRs randomized are each library are different or, where the same CDR is randomized, it is randomized to generate different sequences. Binders from a heavy chain library can then be randomized with CDR diversity in a light chain CDRs by kunkle mutagenesis or by cloning (cut-and-paste, (eg. by ligating

different CDR sequences together)) the new light chain library into the existing heavy chain binders that has only a fixed light chain. The pool can then be further sorted against target to identify binders possessing increased affinity. For example, binders (for example, low affinity binders) obtained from sorting an L3/H3, an  
5 H1/H2/H3 or an L3/H1/H2/H3 library may be fused with library of an L1/L2/H1/H2 or an L1/L2/L3 diversity to replace its original fixed L1/L2/H1/H2 or an L1/L2/L3, wherein the new libraries are then further sorted against a target of interest to obtain another set of binders (for example, high affinity binders). Novel antibody sequences can be identified that display higher binding affinity to either the IGF1 or  
10 mVEGF antigens.

In some embodiments, libraries comprising polypeptides of the invention are subjected to a plurality of sorting rounds, wherein each sorting round comprises contacting the binders obtained from the previous round with a target antigen distinct from the target antigen(s) of the previous round(s). Preferably, but not  
15 necessarily, the target antigens are homologous in sequence, for example members of a family of related but distinct polypeptides, such as, but not limited to, cytokines (for example, alpha interferon subtypes).

#### **Generation of Antibody Variable Domain Libraries**

Antibody libraries can be generated by mutating the solvent accessible  
20 and/or highly diverse positions in at least one CDR of an antibody variable domain. Some or all of the CDRs can be mutated using the methods of the invention. In some embodiments, it may be preferable to generate diverse antibody libraries by mutating positions in CDRH1, CDRH2 and CDRH3 to form a single library or by mutating positions in CDRL3 and CDRH3 to form a single library or by mutating  
25 positions in CDRL3 and CDRH1, CDRH2 and CDRH3 to form a single library.

A library of antibody variable domains can be generated, for example, having mutations in the solvent accessible and/or highly diverse positions of CDRH1, CDRH2 and CDRH3. Another library can be generated having mutations in CDRL1, CDRL2 and CDRL3. These libraries can also be used in conjunction  
30 with each other to generate binders of desired affinities. For example, after one or more rounds of selection of heavy chain libraries for binding to a target antigen, a light chain library can be replaced into the population of heavy chain binders for further rounds of selection to increase the affinity of the binders.

In one embodiment, a library is created by substitution of original amino acids with variant amino acids in the CDRH3 region of the variable region of the heavy chain sequence. According to the invention, this library can contain a plurality of antibody sequences, wherein the sequence diversity is primarily in the CDRH3 region of the heavy chain sequence.

In one aspect, the library is created in the context of the humanized antibody 4D5 sequence, or the sequence of the framework amino acids of the humanized antibody 4D5 sequence. Preferably, the library is created by substitution of at least residues 95-100a of the heavy chain with amino acids encoded by the *DVK* codon set, wherein the *DVK* codon set is used to encode a set of variant amino acids for every one of these positions. An example of an oligonucleotide set that is useful for creating these substitutions comprises the sequence (*DVK*)<sub>7</sub>; an example of an oligonucleotide set having this sequence is oligonucleotide (F63) (SEQ ID NO: 10). In some embodiments, a library is created by substitution of residues 95-100a with amino acids encoded by both *DVK* and *NNK* codon sets. An example of an oligonucleotide set that is useful for creating these substitutions comprises the sequence (*DVK*)<sub>6</sub>(*NNK*); an example of an oligonucleotide set having this sequence is oligonucleotide (F65) (SEQ ID NO: 11). In another embodiment, a library is created by substitution of at least residues 95-100a with amino acids encoded by both *DVK* and *NNK* codon sets. An example of an oligonucleotide set that is useful for creating these substitutions comprises the sequence (*DVK*)<sub>5</sub>(*NNK*); an example of an oligonucleotide set having this sequence is oligonucleotide (F64) (SEQ ID NO: 12). Another example of an oligonucleotide set that is useful for creating these substitutions comprises the sequence (*NNK*)<sub>6</sub>; an example of an oligonucleotide set having this sequence is oligonucleotide (F66) (SEQ ID NO: 13). Other examples of suitable oligonucleotide sequences are listed in Figure 4 and Figure 43 and can be determined by one skilled in the art according to the criteria described herein.

In another embodiment, different CDRH3 designs are utilized to isolate high affinity binders and to isolate binders for a variety of epitopes. The range of lengths of CDRH3 generated in this library is 11 to 13 amino acids, although lengths different from this can also be generated. H3 diversity can be expanded by using *NNK*, *DVK* and *NVK* codon sets, as well as more limited diversity at N and/or C-terminal. Diversity can also be generated in CDRH1 and CDRH2.

In one embodiment of a library, diversity in H1 and H2 is generated utilizing the following oligonucleotides:

The oligonucleotides used for H1: F151 (GCA GCT TCT GGC TTC ACC ATT AVT RRT WMY KMT ATA CAC TGG GTG CGT CAG; SEQ ID NO: 14),  
 5 F152 (GCA GCT TCT GGC TTC ACC ATT AVT RRT WMY KGG ATA CAC TGG GTG CGT CAG; SEQ ID NO: 15), F175 (GCA GCT TCT GGC TTC ACC ATT AVT RVM WMY KMT ATA CAC TGG GTG CGT CAG; SEQ ID NO: 16) and F176 (GCA GCT TCT GGC TTC ACC ATT AVT RVM WMY KGG ATA CAC TGG GTG CGT CAG; SEQ ID NO: 17) were pooled, and for H2,  
 10 oligonucleotides F153 (AAG GGC CTG GAA TGG GTT GST DGG ATT WMT CCT DMT RRC GGC DMT ACT DAC TAT GCC GAT AGC GTC AAG GGC; SEQ ID NO: 18), F154 (AAG GGC CTG GAA TGG GTT GST DHT ATT WMT CCT DMT RRC GGC DMT ACT DAC TAT GCC GAT AGC GTC AAG GGC; SEQ ID NO: 19), F173 (AAG GGC CTG GAA TGG GTT GST DGG ATT DMT  
 15 CCT NMT RRC GGC DMT ACT DAC TAT GCC GAT AGC GTC AAG GGC; SEQ ID NO: 20) and F174 (AAG GGC CTG GAA TGG GTT GST DHT ATT DMT CCT NMT RRC GGC DMT ACT DAC TAT GCC GAT AGC GTC AAG GGC; SEQ ID NO: 21) were pooled.

For diversity in CDRH3, multiple libraries can be constructed separately  
 20 with different lengths of H3 and then combined to select for binders to target antigens. Optionally, in one library, DVK codon sets are utilized in the context of oligonucleotides F163a, F164a, F164b, F165 and F166 (see Figure 4), which are pooled (i.e., the oligonucleotides are used as a single pool). A second library may use the same oligonucleotides as the first library and oligonucleotide F125 (CGR  
 25 TTC ACT ATA AGC CGT GAC ACA TCC AAA AAC; SEQ ID NO: 22). A third library may use oligonucleotides F165a and F165b. A fourth library can be constructed using a pool of *NVT* oligonucleotides with tryptophan doped in the sequences: F103, F134, F135, F155, F156, F157, F160, F160g and F167 pooled together. A fifth library can be constructed using codon sets *NNS* in  
 30 oligonucleotides F66a and F66b.

The multiple libraries can be pooled and sorted using solid support selection and solution sorting methods as described previously and shown in Figure 44 and Figure 45. Multiple sorting strategies may be employed. For example, one variation involves sorting on target bound to a solid, followed by sorting for a tag

that may be present on the fusion polypeptide (eg. anti-gD tag) and followed by another sort on target bound to solid. Alternatively, the libraries can be sorted first on target bound to a solid surface, the eluted binders are then sorted using solution phase binding with decreasing concentrations of target antigen. Utilizing combinations of different sorting methods provides for minimization of selection of only highly expressed sequences and provides for selection of a number of different high affinity clones.

High affinity binders for target antigens can be isolated from the libraries. Limiting diversity in the H1/H2 region decreases degeneracy about  $10^4$  to  $10^5$  fold and allowing more H3 diversity provides for more high affinity binders. Utilizing libraries with different types of diversity in CDRH3 (eg. utilizing DVK or NVT) provides for isolation of binders that may bind to different epitopes of a target antigen.

Of the binders isolated from the pooled libraries as described above, it has been discovered that affinity may be further improved by providing limited diversity in the light chain. Light chain diversity is generated in this embodiment as follows in CDRL1: amino acid position 28 is encoded by RDT; amino acid position 29 is encoded by RKT; amino acid position 30 is encoded by RVW; amino acid position 31 is encoded by ANW; amino acid position 32 is encoded by THT; optionally, amino acid position 33 is encoded by CTG; in CDRL2: amino acid position 50 is encoded by KBG; amino acid position 53 is encoded by AVC; and optionally, amino acid position 55 is encoded by GMA; in CDRL3: amino acid position 91 is encoded by TMT or SRT or both; amino acid position 92 is encoded by DMC; amino acid position 93 is encoded by RVT; amino acid position 94 is encoded by NHT; and amino acid position 96 is encoded by TWT or YKG or both.

In another embodiment, a library or libraries with diversity in CDRH1, CDRH2 and CDRH3 regions is generated. For diversity in CDRH1 and CDRH2, the following oligonucleotides are used: F151 (5'-GCA GCT TCT GGC TTC ACC ATT AVT RRT WMY KMT ATA CAC TGG GTG CGT CAG-3'; (SEQ ID NO: 14) and F152 (5'-GCA GCT TCT GGC TTC ACC ATT AVT RRT WMY KGG ATA CAC TGG GTG CGT CAG-3'; SEQ ID NO: 15) were pooled, and for H2, oligonucleotides 173 (5'-AAG GGC CTG GAA TGG GTT GST DGG ATT DMT CCT NMT RRC GGT DMT ACT DAC TAT GCC GAT AGC GTC AAG GGC-3'; SEQ ID NO: 20) and F174 (5'-AAG GGC CTG GAA TGG GTT GST DHT ATT

DMT CCT NMT RRC GGC DMT ACT DAC TAT GCC GAT AGC GTC AAG  
GGC-3'; SEQ ID NO: 21) were pooled.

In this embodiment, diversity in CDRH3 is generated using a variety of  
lengths of H3 regions and using primarily codon sets *XYZ and NNK or NNS*. The  
oligonucleotides used include F66b, F66d, F66f, F66a<sub>1</sub>, F66b<sub>1</sub>, F66g, F66h, F66i,  
5 F66j, F171c, F171d, F171e, F171, F185, F186, F187, F190, F190a, F190b, F190c,  
F190d, and F190e. (See Figure 4C.) Libraries can be formed using individual  
oligonucleotides and pooled or oligonucleotides can be pooled to form a subset of  
libraries. The libraries of this embodiment can be sorted against target bound to  
10 solid. Clones isolated from multiple sorts can be screened for specificity and  
affinity using ELISA assays. For specificity, the clones can be screened against the  
desired target antigens as well as other nontarget antigens. Those binders to the  
desired target antigen can then be screened for affinity in solution binding  
competition ELISA assay as described in Example 8 or spot competition assay  
15 described in Example 9. High affinity binders for target antigens can be isolated  
from the library utilizing *XYZ* codon sets prepared as described above. These  
binders can be readily produced as antibodies or antigen binding fragments in high  
yield in cell culture.

In some embodiments, it may be desirable to generate libraries with a greater  
20 diversity in lengths of CDRH3 region. For example, it may be desirable to generate  
libraries with CDRH3 regions ranging from about 7 to 19 amino acids. Illustrative  
oligonucleotides useful for this purpose are shown in Figure 43.

High affinity binders isolated from the libraries of these embodiments are  
readily produced in bacterial and eukaryotic cell culture in high yield. The vectors  
25 can be designed to readily remove sequences such as gD tags, viral coat protein  
component sequence, and/or to add in constant region sequences to provide for  
production of full length antibodies or antigen binding fragments in high yield.

A library with mutations in CDRH3 can be combined with a library  
containing variant versions of other CDRs, for example CDRL1, CDRL2, CDRL3,  
30 CDRH1 and/or CDRH2. Thus, for example, in one embodiment, a CDRH3 library  
is combined with a CDRL3 library created in the context of the humanized 4D5  
antibody sequence with variant amino acids at positions 28, 29, 30, 31, and/or 32  
using codon sets as described in Figure 3. Examples of oligonucleotides useful in  
creating these substitutions include those that incorporate these codon sets. In



another embodiment, a library with mutations to the CDRH3 can be combined with a library comprising variant CDRH1 and/or CDRH2 heavy chain variable domains. In one embodiment, the CDRH1 library is created with the humanized antibody 4D5 sequence with variant amino acids at positions 28, 30, 31, 32 and 33 using codon sets as described in Figure 3. Examples of oligonucleotide sets useful in creating these substitutions include those that incorporate these codon sets. A CDRH2 library may be created with the sequence of humanized antibody 4D5 with variant amino acids at positions 50, 52, 53, 54, 56 and 58 using the codon sets described in Figure 3. Examples of oligonucleotide sets useful in creating these substitutions include those that incorporate these codon sets.

Any combination of codon sets and CDRs can be diversified according to the amino acid position selection criteria described herein. Examples of suitable codons in various combinations of CDRs are illustrated in Figures 5-13. Figures 5-7 also include illustrative calculations of designed diversity values of libraries generated according to the choice of codon sets used in the indicated CDRs and amino acid positions.

Having generally described the invention, the same will be more readily understood by reference to the following examples, which are provided by way of illustration and are not intended as limiting.

### EXAMPLE 1

Vectors encoding fusion polypeptides comprising variant CDRs were constructed as follows.

#### Antibody Phage Display Vectors based on pS1607

A vector for antibody phage display was constructed by modifying vector pS1607 (Sidhu et al., J. Mol. Biol. (2000), 296:487-495). Vector pS1607, which has pTac promoter sequence and *malE* secretion signal sequence, contained a sequence of human growth hormone fused to the C-terminal domain of the gene-3 minor coat protein (p3). The sequence encoding hGH was removed, and the resulting vector sequence served as the vector backbone for construction of vectors of the present invention that contain DNA fragments encoding the anti-her2 humanized antibody 4D5 light chain and heavy chain variable domain sequences in the form of:

(i) single chain Fv (scFv) (SEQ ID NO: 23; Figure 14);

(ii) single chain Fv with zipper domain (scFvzip) (SEQ ID NO: 24; Figure 15);

5

(iii) Fab fragment (Fab) (SEQ ID NO: 25; Figure 16);

or (iv) Fab fragment with zipper domain (Fabzip) (SEQ ID NO: 26; Figure 17).

The humanized antibody 4D5 is an antibody which has mostly human  
10 consensus sequence framework regions in the heavy and light chains, and CDR  
regions from a mouse monoclonal antibody specific for Her-2. The method of  
making the anti-Her-2 antibody and the identity of the variable domain sequences  
are provided in U.S. Pat. Nos. 5,821,337 and 6,054,297. The resulting vectors  
(schematically illustrated in Figures 34A-D) comprise the humanized antibody 4D5  
15 variable domains under the control of the IPTG-inducible Ptac promoter (sequences  
as shown in Figures 14-17) or the alkaline phosphatase phoA promoter (as described  
in U.S. Pat. No. 5,750,373).

20 **Construction of Fab-zip construct and characterization of its function in phage display**

Construction of an example of a vector is described in greater illustrative  
detail below for Fab-zip. Inclusion of the zipper region facilitates the formation and  
display of dimers of ScFv and F(ab) to form scFv<sub>2</sub> and F(ab')<sub>2</sub>, respectively.

Fab-zip vectors were constructed as described below and shown in Figure  
25 34B.

## METHODS AND MATERIALS

Construction of Anti-Her2 F(ab')<sub>2</sub> vector: A phagemid construct comprising a sequence encoding an anti-Her2 polypeptide under the control of the Ptac promoter was generated using vector pS1607 as the backbone, as described above. male secretion signal sequence was first fused to the N-terminal sequence of light chain (LC) to direct the LC synthesis to the periplasm of bacteria cell. A gD tag was added at the C-terminus of LC. Following the stop codon of LC, another ribosome binding site and STII signal sequence were fused to the N-terminus of heavy chain (HC) sequence and continued with the C-terminal domain of the pIII, a minor coat protein of M13 phage.

To generate F(ab')<sub>2</sub> displayed on phage, the dimerizable leucine zipper GCN4 sequence was utilized. Cassette mutagenesis was performed to insert in between HC and pIII first the hinge sequence that came from full length IgG1 antibody (TCPPCPAPELLG (SEQ ID NO: 27)) followed by GCN4 sequences (GRMKQLEDKVEELLSKNYHLENEVARLKKLVGERG (SEQ ID NO: 3)). The GCN4 leucine zipper was expected to bring two sets of LC/HC-pIII fusion polypeptides together in the *E. coli* periplasm, which would allow the formation of disulfide bonds in the hinge region to secure the dimer formation before and after getting out of the *E. coli* periplasm.

Two versions of the vector schematically illustrated in Figure 34B were made. One had an Amber stop codon (TAG) after the GCN4 zipper sequence and one did not. These two constructs would theoretically produce one or both of the divalently displaying phage as depicted in Figure 18. The Amber-less construct would make only the form (C) that would have two copies out of the five copies of pIII on phage as fusion polypeptide which would be stabilized with both the hinge disulfide and GCN4 zipper. The construct with Amber after the GCN4 should be able to produce either form (B) or (C) of the phage depending on the efficiency of suppression of the Amber stop codon in XL-1 bacterial strain.

The formation of F(ab')<sub>2</sub> on phage: To demonstrate the formation of F(ab')<sub>2</sub>, or the divalent display of F(ab') on the phage, the expected function of divalent display was measured. With the avidity effect of divalent display, the phage binding to ligand-modified solid phase should demonstrate significantly decreased off-rate, the rate at which it detaches off the solid phase, if the density of the ligand on the solid support is high enough to allow divalent binding. For divalent interaction to

detach off the plate, both interactions have to be broken simultaneously for the phage to come off, which predictably would occur with much less frequency.

To produce displaying phage, *E. Coli* strain XL-1 Blue (Stratagene, San Diego, CA) infected first with F(ab) or zipped F(ab')<sub>2</sub> phage and then VCS helper phage (Stratagene, San Diego, CA) were grown in 2YT media at 37°C for 20 h and  
5 phage was harvested as described (Sidhu et al., Methods Enzymol. (2000), 328:333-363). Briefly, phage was purified by first precipitating them from the overnight culture media with polyethylene glycol, and resuspended in PBS. Phage were quantitated by spectrophotometer with its reading at 268nm (1 OD=1.13X10<sup>13</sup>/ml).  
10 Phage ELISA (Sidhu et al., supra) was first performed by titrating the phage in phage ELISA binding buffer (PBS with 0.5% BSA and 0.05% Tween 20) and its binding to ligand (Her-2 extracellular domain, Her-2ECD) coated on 96-well plate was quantified by HRP conjugated anti-M13 antibody followed by adding the peroxidase substrate, H2O2 and TMB (Kirkgaard) which can be read at wavelength  
15 450nm. The plate was coated with Her-2ECD at 2µg/ml in PBS for 2h at room temperature or 4°C overnight, which is sufficient to allow divalent binding. We blocked the plate with 0.5% BSA and then 0.2% Tween20 for 1 hour before adding phage dilutions to the wells.

For the off-rate plate binding experiments or solution binding competition  
20 ELISA, a phage concentration was used of either F(ab) or zipped F(ab')<sub>2</sub> which gave about 90% of maximum binding to the coated plate. To show that the F(ab')<sub>2</sub> phage still maintain the same binding affinity where avidity plays less of a role, competition ELISA was performed by incubating the F(ab) or zipped F(ab')<sub>2</sub> phage with increasing concentrations of Her-2ECD ((0.1 to 500nM) in solution for 5 hours  
25 at 37°C. The unbound phage was captured briefly (15 min.) with plates coated with Her-2ECD and measured with HRP-anti-M13 conjugate. The IC<sub>50</sub>, the concentration of Her-2ECD that inhibits 50% of the F(ab)-phage, represents the affinity (see Figure 19).

For the off-rate experiment, F(ab) or zipped F(ab')<sub>2</sub> phage was allowed to  
30 bind to Her-2ECD coated wells first, which were then washed to get rid of excess phage. Serial dilutions of Her-2ECD (0.1nM to 500 nM) were added to the well and incubated for 5 hours at 37°C, during which time the phage was allowed to detach off the plate and the rebinding was inhibited by the Her-2ECD in the solution. Phage that still remained on the plate was then quantified with HRP-antiM13

conjugate. The relative proportion of remaining phage was calculated by dividing the OD at the particular Her-2ECD concentration with OD in the absence of Her-2ECD and shown as % in the Figure 20.

Another way to demonstrate the divalency of F(ab')<sub>2</sub> phage was to show a difference in the amount of phage that is required to give detectable binding on the ligand coated solid support by standard phage ELISA method as compared to its non-divalent counterpart. We also examined the detectability of low affinity binder. We generated a humanized antibody 4D5 mutant by Kunkel site-directed mutagenesis (Kunkle et al., 1985) in its heavy chain with Arginine 50 changed to Alanine (R50A), in both F(ab) and zipped F(ab')<sub>2</sub> format. Standard phage dilution versus its binding signal on Her-2ECD coated plate phage ELISA was performed (Figure 21 and Figure 22). The display level of the mutant was equivalent for these two formats judged from its binding to antibody to gD tag.

### Results

Binding properties: The zipped F(ab')<sub>2</sub> displaying phage has essentially indistinguishable affinity (1nM) in solution as F(ab) phage (Figure 19). This means that the insertion of hinge and GCN4 zipper to the C-terminus of HC did not perturb its binding capability. However, the avidity effect of the divalent zipped F(ab')<sub>2</sub> is clearly demonstrated by the significantly different behavior from the monovalent F(ab) phage in the plate binding experiments (Figure 20 and 21). In Figure 20, zipped F(ab')<sub>2</sub> phage of either construct with or without amber stop codon after the leucine zipper has a much slower rate of detachment from the ligand coated plate than F(ab) phage. In Figure 21, we saw a consistent 40-50 fold difference in the concentration of phage concentration to achieve the same binding signal. The binding of a low affinity R50A (650nM) binder can be detected and captured at 40-50 fold lower concentration of phage with divalent F(ab')<sub>2</sub> display (Figure 22). This difference is commonly seen comparing monovalent and divalent interaction, e.g. F(ab) vs. M(ab).

### Phage Display Vectors based on Vector pS0643

Construction of Anti-Her2 Fab and F(ab')<sub>2</sub> phagemid: The phagemid vector, pS0643 (also known as phGHam-g3, e.g., United States Patent 5,688,666), contains pBR322 and fl origins of replication, an ampicillin resistant gene, an E. coli alkaline phosphatase (phoA) promoter (Bass et al., (1990) *Proteins* 8:309-314), and a

sequence encoding a stII secretion signal sequence fused to residues 1-191 of human growth hormone (hGH) and a sequence encoding the C-terminal residues 267-421 of protein III of M13 phage (hereinafter, cP3). The pS0643 phagemid also contains an XbaI site and an amber stop codon following residue 191 of hGH. The stII secretion  
5 signal sequence can export a protein to the periplasm of a bacteria cell (e.g., a light chain region (LC) of an antibody). The sequence encoding the human growth hormone (hGH) was removed from the pS0643 vector and replaced with a NsiI/XbaI nucleic acid fragment encoding a humanized anti-Her2 Fab fragment ("h4D5" sequence) ligated in frame with the stII secretion signal (humAb4D5-8, *see* Carter et  
10 al., (1992) PNAS 89:4285-4289, Table 1 and FIGURE1 therein or U.S. Patent No. 5,821,337, for sequence).

The h4D5 antibody is a humanized antibody that specifically recognizes a cancer-associated antigen known as Her-2 (erbB2) developed as described previously. The h4d5 was obtained by polymerase chain reaction using the  
15 humAb4D5 version 8 ("humAb4D5-8") sequence and primers engineered to give rise to a 5' NsiI site and a 3' XbaI site in the PCR product (Carter et al., (1992) PNAS 89:4285-4289). The PCR product was cleaved with NsiI and XbaI and ligated into the pS0643 phagemid vector.

The pS0643 plasmid containing humanized 4D5 (version 8) was still further  
20 modified. The LC was changed at residues 30, 66 and 91 by site-directed mutagenesis. Specifically, residue 30 was changed from asparagine to serine, residue 66 was changed from arginine to glycine, and residue 91 was changed from histidine to serine. These changes were made to increase the expression or the display of Fab on phage to improve the performance of the library and to convert the  
25 framework (66) back to the human consensus framework. Finally, the amber stop codon and XbaI site was removed from C-terminal end of the heavy chain.

A herpes simplex virus type 1 glycoprotein D epitope tag (gD tag) was added in frame to the C-terminus of the LC using site-directed mutagenesis. Following the stop codon downstream of the LC, a ribosome binding site and nucleic acid  
30 molecule encoding a stII signal sequence were ligated to the N-terminus of the HC sequence. Consequently, the HC sequence is in frame with the C-terminal domain of the p3 (cP3), a minor coat protein of M13 phage. Thus, a Fab displayed on phage can be produced from one construct. This Fab phagemid vector is referred to as

pV0350-2b. The sequence of this vector is shown in Figure 37 and has SEQ ID NO: 28.

To generate  $F(ab')_2$  displayed on phage, the PV0350-2b vector was further modified by inserting a dimerizable leucine zipper GCN4 sequence (GRMKQLEDKVEELLSKNYHLENEVARLKKLVGERG) (SEQ ID NO: 3) between the HC and cP3 sequences by cassette mutagenesis. The GCN4 leucine zipper brings two sets of LC/HC-cP3 fusion polypeptides together in the *E. coli* periplasm and presents the dimer on the surface of phage. This  $F(ab')_2$  phagemid vector is referred to as pV0350-4. The sequence of this vector is shown in Figure 38 and has SEQ ID NO: 29.

Vectors based on either ps1607 or ps0643 have been designed including restriction sites that allow for removal of the viral P3 sequences, leucine zipper and gD tag. The variable region domains from heavy and light chain can then be combined with constant region sequences to allow for expression of the variable region domain as Fab fragments or full-length antibodies. Sources of constant region sequences are known to those of skill in the art.

## **EXAMPLE 2**

### **Modifications to Dimerization Domains**

A series of mutations were made in the dimerizing domain, which for example, include the hinge region plus GCN4 leucine zipper for constructs such as Fab-zip as described in Example 1. The mutations were made to the dimerization domain to determine if both a disulfide bond as well as the zipper region were important to the display of  $F(ab')_2$  or ScFV<sub>2</sub>.

A series of mutations (Fig. 39) was made in the dimerization domain, i.e. hinge region plus GCN4 leucine zipper, and their effects on avidity were examined (Fig 40). The phagemid vector phGHam.g3 with alkaline phosphatase (phoA) promoter was used as described previously since it is less toxic to bacterial cells and increases the phage yield compared to a vector with Ptac promoter (C. V. Lee, unpublished observation). The solution binding of all constructs was first examined to make certain the change in the construct did not disrupt the folding and function of the Fab. IC50s for all variants were between 0.05-0.07 nM measured at room temperature, which agreed well with K<sub>d</sub> of h4D5 (0.1nM).

The mutations were designed to examine the function of hinge region and leucine zipper in Fab'-zip phage in its bivalency. Constructs include a construct that has 1) that has the hinge region and the leucine zipper, Fab'-zip ;2)both cysteines in hinge region mutated to alanine (Fab'(C→A)-zip), 3) has the whole hinge region deleted (Fab-zip), 4) the hinge deleted leaving the first cysteine (Fab-C-zip), or 5) has both hinge and zipper deleted leaving a single cysteine (Fab-C). All of these constructs were made with or without amber stop codon before cP3 (C- terminal region of viralcoat protein p3)since the presence or absence of stop codons allows for the examination of the dependence of avidity on the interchain covalent bond between two Fabs. Avidity assay was performed as described in Example 1. Avidity index represents a measurement of functional avidity of individual construct and is defined as the percent phage bound to the immobilized antigen after the chase of 500nM erbB2. High avidity is a functional consequence of displaying two copies of Fab per phage.

Without an amber stop codon, all constructs present Fab with significantly higher avidity than Fab-phage (Fig. 40). These results indicate that the probability of incorporating two copies of cP3 fusion on phage coat increases when the following are present: hinge plus zipper (Fab'-zip), cysteine-free hinge plus zipper (Fab'(C→A)-zip), zipper alone (Fab-zip), one cysteine plus zipper (Fab-C-zip) or just one cysteine (Fab-C) by itself between Fab and cP3. When both Fab' or Fab fusions are covalently linked to cP3 (no amber stop codon), bivalent display does not require the additional covalent links provided by the hinge region disulfides. However, the presence of an interchain covalent bond does appear to improve the frequency of incorporating two copies of fusion per phage since constructs that lack a cysteine residue such as, Fab'(C→A)-zip and Fab-zip (without amber stop), exhibited reduced avidity compared to Fab'-zip or other constructs that have disulfide bond in the linker, despite the fact that they do have significantly higher avidity than Fab-phage (no amber).

With the presence of an amber stop codon before cP3, most proteins were expressed into periplasm and associated with cP3 fusion protein via leucine zipper and/or disulfide bond since the read through of amber stop codon in the amber-suppressor strain XL-1 blue occur only at ~10% frequency. It is expected that a dimer should be linked to phage by single copy of cP3 as depicted in Fig. 18 and the bivalency be formed by forming an interchain covalent bond because the



concentration of phage exuded into bacterial growth media is in the sub-nanomolar range, and thus, the binding energy of the leucine zipper interaction would not be sufficient to maintain the dimer during overnight growth at 37°C. Indeed, it was observed that those constructs that do not have disulfide bond in the hinge  
5 (Fab'(C→A)-zip) or with hinge deleted (Fab-zip) lose the bivalent dependent avidity in the presence of an amber stop codon. The constructs that contain disulfide bonds between Fab and cP3 maintained a high avidity of bivalency in the presence of an amber stop codon.

The exception is Fab-C. It was surprising that Fab-C, with just one cysteine  
10 between Fab and cP3, exhibited such high avidity, if not higher, as compared to the original Fab'-zip phage with full hinge and leucine zipper. These results suggest that Fab-C as cP3 fusion has good probability to associate with another cP3 fusion and get incorporated in the phage coat as dimers. However, the presence of amber stop between cysteine and cP3 in Fab-C construct reduced the avidity to the level of  
15 Fab-phage since most proteins were expressed as free Fab-C and the chance of free Fab-C in the periplasmic space forming dimer with a Fab-C-cP3 fusion appears to be very low.

The minimum element for bivalent display is either leucine zipper alone (Fab-zip) or one disulfide bond (Fab-C). When Fab-C is compared to Fab-zip, the  
20 results show that the disulfide bond is more effective in some circumstances to improve avidity than leucine zipper alone.

### Western blot analysis

Western blotting was used to examine whether these constructs were  
25 displayed as covalently-linked dimers. We analyzed phage constructs Fab, Fab'-zip, Fab'(C→A)-zip, Fab-zip, Fab-C-zip, or Fab-C with or without amber stop codon. Phage samples ( $3 \times 10^{11}$ ) were denatured, subjected to SDS-PAGE and transferred to PVDF filters, which were then probed with either antibody that recognized the gD-tag, which was fused to the C-terminus of the light chain (Figure 41 A and C), or  
30 antibody to phage coat protein P3 (Mobi-Tech) (Figure 41 B and D).

Under reducing conditions (+DTT), the disulfide bond linking the light chain to the heavy chain fusion was reduced, and anti-gD blot (Figure 41C) showed a single band with an apparent molecular weight (MW) of ~25 kDa, which was in good agreement with the calculated MW of a light chain plus gD-tag (26 kDa).

When blotted with anti-P3, full length P3 (MW 48 kDa) supplied by helper phage and heavy chain-cP3 (MW 43-45 kDa depending on constructs) fusion in the reduced condition was expected. The results in Figure 41D showed a main band at 60 kDa representing P3 and lower band with 50-52 kDa representing the fusion, based on the comparison with K07 alone (data not shown); both are greater than the calculated MW of the two main species expected. However, P3 is known to exhibit an anomalously high apparent MW under SDS-PAGE conditions {Gray, 1981 et al. 1981 J. Mol. Biol. 146:621-627; Crissman, 1984, Virology 132:445-455}. Further, the relative position of the 50-52 kDa bands seems to correlate with the MW of the expected heavy chain-cP3 fusion of each construct with various insertions. It is interesting to note that the same 50-52 kDa band in the non-reduced gel blotted with anti-P3 was observed (Figure 41 B), which suggests that there are some heavy chain-cP3 fusion proteins that were not covalently linked with its light chain. Non-covalent linked light chain (25 kDa) was also observed in the non-reduced gel blotted with anti-gD antibody. (See Figure 41 A) In the reduced gel, the intensities of the 50-52 kDa bands from anti-P3 blot and the light chain bands from anti-gD blot indicate the level of display as Fab fusion for individual construct.

In general, adding amber stop codon reduced the display for all constructs as expected since the read-through of the amber stop codon is infrequent in amber suppressor strain. The insertion of the full dimerization domain (hinge and zipper) as in Fab'-zip reduces the display, and the culprit seems to reside in the two disulfide bonds in the hinge region since replacing the cysteine as in the Fab'(C→A)-zip or deleting the whole hinge (Fab-zip) increased most of the display to that of Fab-phage. Having just one cysteine in the dimerization domain appears to be well tolerated and displays well as in Fab-C-zip or Fab-C construct. The results show that reducing the number of disulfide bonds to one or zero increased expression of the fusion proteins.

Under non-reducing conditions (-DTT), interchain disulfide bonds were preserved and different patterns of bands for each of the constructs were observed (Figure 41 A and B). As is often the case in western blots of phage preparations(Gray, 1981 supra;Crissman, 1984, supra), multiple bands can be observed resulting from proteolysis. However, comparing the highest MW major band in each lane should indicate the different products of the constructs as the intact cP3 fusion. Fab-phage produced a band with an apparent MW of 95 kDa,

which was detected with both anti-gD and anti-P3 antibodies and agrees well with the calculated MW of 75 kDa of Fab-cP3 fusion. Again, the P3 fusion protein seems to have an effect on the mobility on SDS-PAGE system. In contrast, the Fab'-zip phage (-amber stop) contained a pair of bands with apparent MWs of ~180 and ~200 kDa which is in close agreement with the calculated MW of a dimeric Fab'-zip-cP3 fusion (155 kDa). It is interesting to note that the equivalent construct with amber stop codon produced only the 180 kDa band, which could represent the expected dimer fused to single cP3 as a monovalently displayed dimer complex depicted in Fig. 18. In any case, the covalently linked dimer is formed regardless of the presence of amber stop codon, which is expected since the leucine zipper promotes the dimer formation independent of any covalent link with phage coat in the periplasmic space and, functionally, avidity was observed with this set of constructs. Some lower MW bands were also seen which might be from proteolysis or alternatively disulfide bonded forms. There is a major band at 98 kDa which migrated slightly higher than Fab-cP3 but comigrated with the major band of Fab'(C→A)-zip construct, and would be the monomeric Fab'-zip-cP3 fusion which as expected is stained by anti-gD and anti-P3. So the expression of Fab'-zip fusion is reduced relative to Fab and there is significant portion of fusion protein that did not form disulfide bond.

With constructs Fab' (C→A)-zip and Fab-zip, a major band that migrated slight higher than Fab-cP3 at 98 kDa or 97 kDa individually was observed. These bands are the expected product for constructs with or without amber stop because there is no possibility of covalent disulfides between the two Fab moieties. The presence of dimeric Fab on Fab'(C→A)-zip and Fab-zip phage can not be observed in SDS-PAGE gel because of the lack of disulfide bond. Yet, the functional avidity suggests that the proportion of phage containing two copies of fusion is higher than Fab phage due to the presence of leucine zipper.

Constructs Fab-C-zip and Fab-C contain one interchain disulfide bond, and produce more covalently linked dimers as represented by the 180-200 MW band than Fab'-zip, which have two disulfide bond in the hinge linker. The increase of the covalent-linked dimers correlates with the overall increase of expression of the fusion including the monomer as shown in the 97 and 95 kDa band. It is interesting to note that the proportion of dimer is higher in Fab-C-zip than Fab-C, which suggests that leucine zipper, although not required, does improve the association of

the fusion and the efficiency of forming interchain disulfide bond. Yet the net expression of Fab-C-cp3 fusion is slightly higher than Fab-C-zip construct.

Thus, western blotting suggests the presence of bivalent moieties displayed on Fab'-zip, Fab-C-zip, and Fab-C phage, mirroring what is observed functionally in avidity assays. For constructs, for which the dimer can not be observed on SDS-PAGE, like Fab'(C->A)-zip and Fab-zip, the avidity assay is relied upon to demonstrate its bivalency. The avidity assay shows the consequences of presenting two copies of Fab per phage particle since all constructs have same solution binding affinity and the avidity is not influenced by the display level. Net expression of Fab'-zip can be significantly improved by minimizing the dimerization domain. Potentially, the different extent of dimer display and avidity of these various constructs may provide useful tools for applications that may call for different extent of display and avidity.

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### EXAMPLE 3

Libraries of antibody variable domains were generated to isolate and screen for isolation of high affinity binders to particular target antigens. Diversity of antibody variable domains is preferably generated in CDR regions of the heavy and/or light chain variable domains. Generation of diversity in CDR regions of heavy chains is described below. Utilization of a single template molecule as the backbone for generation of the diversity in CDR regions is preferred because the single template can be modified to improve display and folding and may accommodate H3 regions of various sizes.

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#### **Library Design: H1, H2**

Libraries of antibody variable domains were designed to maximize diversity in the heavy chain CDR regions while minimizing structural perturbations in the antibody variable domains. Structural perturbations in antibody variable domains are generally associated with improperly folded antibody domains resulting in low yield and unstable products, for example when produced in bacterial cells. Low yields decrease the number of binders detected in screening. Improperly folded and unstable antibody structures also can result in low yields and low affinity when antibodies are produced as Fab fragments or full-length antibodies in cell cultures. Production of properly folded antibodies in high yield in cell culture is desirable especially in the case of antibodies useful therapeutically.

Diversity in the CDR regions was generated by identifying solvent accessible and highly diverse positions in each CDR for CDRs H1 and H2 of the template molecule, and designing an oligonucleotide comprising at least one tailored (i.e., non-random) codon set encoding variant amino acids for the amino acid position corresponding to the position of at least one solvent accessible residue at a highly diverse position in at least one CDR region. A tailored codon set is a degenerate nucleic acid sequence that preferably encodes the most commonly occurring amino acids at the corresponding positions of the solvent accessible residues in known, natural antibodies.

Solvent accessible residues in the CDRs were identified in the antibody variable domain template molecule by analyzing the crystal structure of the template molecule. Humanized antibody 4D5 is efficiently produced and properly folded when produced in a variety of host cells, including bacterial cell culture. The crystal structure for the humanized antibody 4D5 variable region is known and publicly available at [www.rcsb.org](http://www.rcsb.org) (accession code IFVC).

The solvent accessible positions in the CDRs of the light chain and CDRH1 and CDRH2 of the heavy chain were identified using the Insight II program (Accelrys, San Diego, CA).

CDR residues were also analyzed to determine which positions in the CDRs were highly diverse. Highly diverse positions in the CDR regions for the heavy chains were identified by examining the sequences of known, naturally occurring antibodies in the Kabat database. The Kabat database is available at [immuno/bme/nwu/edu](http://immuno/bme/nwu/edu). In the Kabat database, there were about 1540 sequences of the human light chain and 3600 sequences for the human heavy chain. The CDR sites were aligned and numbered as described by Kabat (see [immuno/bme/nwu/edu](http://immuno/bme/nwu/edu)). Highly diverse amino acid positions were identified by lining up and ranking the amino acid usage, from most frequently used to less frequently used for each CDR residue. For example, H1-30 (i.e., residue 30 of the heavy chain CDR1) was found to be S (serine) in 2451 out of 3617 antibody sequences in the Kabat database, and it is the amino acid found most frequently at this position. Next on the list of frequency is threonine (occurring in 655 sequences), followed by asparagine (154 sequences), arginine (70 sequences), glycine (67 sequences), with the remaining 128 sequences being one of the remaining amino acids. Illustrative diverse sites, with

corresponding diversity list of amino acids, are shown in Figure 2 (for the heavy chain).

Amino acid residues found in a particular position that collectively constitute the most frequently occurring amino acids among the known, natural antibody sequences are selected as the basis for library design. The most frequently occurring amino acids were deemed to be those that are most commonly found in the top 90% of the list of diverse amino acids at that position (this group of amino acids is referred to herein as “target group of amino acids”). However, as described herein, the percent cutoff for a target group of amino acids can be varied, as described above, according to the circumstances and purpose of the diversity library that is to be achieved.

For humanized antibody 4D5, the positions identified as solvent accessible and highly diverse were:

	Heavy Chain	
15	CDR 1	28, 30, 31, 32
	CDR2	50, 52, 53, 54, 56, 58

Examples of amino acids that occur at high frequency in natural diversity (i.e., among known, natural antibody sequences) (referred to as “target group” or “natural diversity” in Figure 3), and the designed diversity of amino acids by DNA codons (“Diversity<DNA codon>”) for each of these positions is shown in Figure 3.

Codon sets encoding a specific group of amino acids were designed to include at least a certain percentage of the amino acids in the known, natural sequences (designated as “% covering” in Figure 3). Of the amino acids encoded by a codon set, at least about 40% of the amino acids are target amino acids identified for a particular solvent accessible and highly diverse position (designated as “% good” in Figure 3; amino acids encoded by a codon set that are target amino acids are shown in bold in column 3 of Figure 3), more preferably any one of 40 to 100%, more preferably 70%. However, as described herein, the % good value can be varied according to circumstance and objectives. The codon sets were selected such that they preferably encoded the amino acids with the highest occurrences at a particular position. The number of non-target amino acids coded by a codon set for a particular position was minimized. Effectiveness of codon set selection/design was evaluated in part based on the “% good” value. A high percentage meant very low non-target amino acids; a high value of “% good” was deemed more important

than having more target amino acids among the amino acids coded by a particular codon set. Redundancy was included in calculating the “% good” value. For evaluation purposes, the “% covering” value was also calculated. This value represents the percentage of natural diversity covered by the “good” or target amino acids encoded by a particular codon set. For example, for H-30, when codon set *RMV* is used, the “good” amino acids are STNRDG, which is 73% (% good) of the amino acids encoded by the codon set. STNRDG are amino acids that cover 3489 out of 3617 known, natural antibody sequences at this amino acid position. 3489/3617 equals 96%, which is the “% covering” value. Thus, in one design using *RVM* at H-30, 73% of the library covers 96% of the natural diversity in CDRH1 at position 30.

The codon sets were also designed to exclude, when possible, cysteine and stop codons. The presence of cysteine residues tends to cause folding problems and stop codons can decrease the effective library size. In the design of the codon sets, it was also deemed desirable to minimize the number of nontarget amino acids.

The codon sets designed for each solvent accessible and highly diverse residue of humanized antibody 4D5 are shown in Figure 3. At any particular residue, one or more codon sets could be used depending on the target amino acids that were identified. For example, combining two H1 oligonucleotides, one having residue H1-33 as *KMT*, the other having H1-33 as *KGG*, results in 100% of the codons used for H1-33 covering 86% (50% + 30%) of the natural diversity at the H1-33 position. Other examples of instances where two codon sets can be beneficially used include using codons *DGG* and *DHT* at H2-50.

The various codon sets could be used to generate diverse libraries with diversity in one or more CDR regions, including CDRH1 and CDRH2. For example, Figures 5-13 and Figure 24 show various illustrative versions of codon set designs that can be used to generate diversity. Figures 3A and 3B provide a summary of the amino acid coverage of these designs. In general, it is preferable, but not necessary, that the designs narrow the diversity to cover more of the natural diversity and exclude as much as possible the “non-target” amino acids.

### Library Design: H3

In comparison to other CDRs, heavy chain CDR3 (H3) regions exhibit the greatest diversity in sequences and lengths, although the sequence diversity is not completely random (i.e., some amino acids were found to occur more often than other in particular amino acid positions). Because of this diversity in sequences and sequence lengths, it is difficult to design a strategy that provides for diversity in H3 region. Using a single antibody template molecule allows for a strategy that includes different lengths of H3 because the template can be selected and designed to accommodate H3 regions of varying lengths in the initial design of the library.

10 The template is selected to accommodate different lengths of H3 region while maintaining good structural characteristics of folding and stability. The diversity in the H3 region is preferably tailored to mimic natural diversity, although different libraries generated with different codon sets can also be used to develop antibodies that bind to a variety of different epitopes in the target antigen or to provide for

15 isolation of more binders having unique H3 sequences.

In a preliminary analysis to assess the amino acid preferences for each position in H3, a library with diverse H3 was generated using an *NNK* codon set for residues 95-100a of the humanized antibody 4D5 H3 region. The *NNK* codon set encodes all 20 amino acids and stop codons. This library was generated in a Fab

20 phage display format and 400 clones that displayed functionally on phage were identified and sequenced. The amino acid sequence found in H3 regions in the *NNK* library were compared to those found in the Kabat database. A comparison of those amino acids is shown in Figure 23. When the amino acid sequences in the *NNK* library and Kabat database were analyzed, it was determined there was good

25 agreement in most amino acid usage between the library sequences and the sequences of Kabat. Interestingly, there appeared to be more aliphatic/hydrophobic amino acids in the *NNK* library than in the known, naturally occurring sequences. See Figure 23.

Diversity in H3 was also determined using codon sets *DVK* and *XYZ*. The

30 amino acid frequency for each amino acid in the H3 region randomized with *DVK* or *XYZ* was identified and compared to the amino acid frequency of naturally occurring antibodies in the Kabat database as described above. The results are shown in Figure 42. The results show that both the *DVK* and *XYZ* library had amino acid usage that was generally in good agreement with that of naturally occurring



antibodies. The *DVK* library did show decreases in usage of tyrosine, leucine, valine and isoleucine. The *XYZ* library also showed less frequent usage of tyrosine.

Codon sets are identified by 3 capital letters in italics(eg. *DVT*, *NNK*, *NVT*).

These letters refer to generic codon formulas as follows: R is 50%A/50%G; M is

5 50%A/ 50%C; K is 50%G/ 50%T; S is 50%G/50%C; W is 50%A/ 50%T; H is 33%A/33%T/33%C; B is 33%G/33%T/33%C; V is 33%G/33%A/33%C; D is 33%G/33%A/33%T; N is any nucleic acid; X is 38%G, 19% A, 26% T, and 17%C; Y is 31% G, 34%A, 17% T, and 18%C; and Z is 24%G/76%C.

10 Codon sets that resulted in similar amino acid usage in H3 as compared to natural diversity were then used to design libraries containing diversified H3. These codon sets include *NNK*, *NNS*, *NVT*, *DVK* and *XYZ*. In some embodiments, codon sets encoding all 20 amino acids at a position, such as *NNK* or *NNS* were utilized as shown in Figure 4.

One of the codon sets was *DVK*. *DVK* encodes ACDEGKNRSYW and a  
15 stop codon. Amino acids that do not occur frequently in known, natural antibody sequences were excluded, for example, LPHQFIMV. Oligonucleotides encoding H3 regions of varying lengths utilizing *DVK* codons are shown in Figure 4. In one embodiment, a pool of oligonucleotides including F59, F63, F64, F65, F66, and F78 were utilized to form a library of molecules with diversity in H3.

20 Another codon set used was *NVT*. *NVT* encodes ACDNGHPRSTY and excludes W (tryptophan) and a stop codon. Tryptophan is favored in phage display and tends to dominate. Stop codons can decrease library diversity. In some instances, the *NVT* design was doped with W by walking W across the residues. Oligonucleotides encoding H3 regions of oligonucleotides including F134, F136,  
25 FF137, F138, F142, F155, F156, F157, F158, F160 and F160g were utilized to form a library of molecules with diversity in H3.

In another embodiment, a codon set *XYZ* was used as shown in the oligonucleotides represented in Figure 4 and Figure 43. The codon set *XYZ* encodes all 20 amino acids.

30 In terms of which residues to diversify in H3, it was determined that the C-terminus of H3 can be less diversified. In some embodiments, the H3 C terminal was held constant. The C-terminus of H3 had mainly two types of sequences in the Kabat database, the sequences being either:

$Y_{100a}AMD_{101}(Y/V)_{102}$  (sometimes  $Y_{100a}$  can vary slightly)  
or  $F_{100a}D_{101}(Y/V)_{102}$ .

In humanized antibody 4D5, the C-terminus of H3 is YAMDY. The libraries were  
5 designed to keep this part mostly constant, except  $Y_{100a}$  was varied.  $Y_{100a}$  was  
varied using a variety of codon sets such as *DVK*, *DSG*, *KSG*, *NVT* and *XYZ*.  
Alternatively, single amino acid substitutions at this residue can be made with  
substitution of Y with glycine, serine, alanine, tryptophan, valine or aspartic acid.

Libraries were generated using oligonucleotides that encode different  
10 sequence lengths in the H3 region. H3 lengths in naturally occurring antibodies  
range from about 2 amino acids to about 24 amino acids. A series of  
oligonucleotides was prepared encoding H3 regions of varying lengths from about 7  
amino acids to about 19 amino acids as shown in Figure 43. These oligonucleotides  
also provided for limited variation at the C-terminal end. Less diversity is found at  
15 the C-terminal end but the oligonucleotides provide for variation at the C-terminal  
end of YAMD (Y/V) or FD(Y/V). Variations at the 100a and/or 100b position were  
also included. The H3 residues that were varied were varied using codon sets *NNK*,  
*NNS*, *XYZ* or mixtures thereof. Other examples including varying lengths of H3  
regions are shown in Figure 4. In Figure 4, the HC region varies from about 11 to  
20 13 residues some embodiments have the more constant C-terminal of YAMDY.  
Some variation is provided at the residue position 100a(Y). The CDRH3 amino acid  
positions are varied using codon sets such as *DVK*, *NVT*, *NNK*, *XYZ* and *NNS* or  
mixtures thereof.

In one embodiment, multiple libraries were prepared with diversity in the H3  
25 in both sequence and length using each of the oligonucleotides shown in Figure 43.  
These libraries provide diversity in the sequence and length of the H3 region.  
Diversity was also generated in the H1/H2 regions as described previously. The  
libraries were pooled and then sorted against target antigen murine or human VEGF.  
The high affinity and specific binders were isolated and sequenced. Isolating and  
30 sequencing the binders allows identification of the optimal length of the H3 for  
binders to murine or human VEGF was about 11 to 13 amino acids. (Data not  
shown)

In some designs, framework residue 93 was changed to alanine to reflect the  
natural consensus (humanized antibody 4D5 has the mouse residue serine).

Framework residue 94 (right before the first H3 residue) was designed to be arginine, or arginine and lysine (using codon ARA) to reflect the natural sequence consensus. In addition, in some embodiments, 3 amino acids at the N-terminus of the heavy chain were removed right after the secretion signal.

5

#### **EXAMPLE 4**

##### **Library Design: L1, L2, L3**

Libraries of antibody variable domains were designed to maximize diversity in the CDR regions of light chains while minimizing structural perturbations in the antibody variable domains. Structural perturbations in antibody variable domains are generally associated with improperly folded antibody domains resulting in low yield, for example when produced in bacterial cells. Low yields decrease the number of binders detected in screening. Diversity in the CDR regions was generated by identifying solvent accessible and highly diverse positions in each CDR for CDRs L1, L2 and L3, and designing an oligonucleotide comprising at least one tailored (i.e., non-random) codon set encoding variant amino acids for the amino acid position corresponding to the position of at least one solvent accessible residue at a highly diverse position in at least one CDR region. A tailored codon set is a degenerate nucleic acid sequence that preferably encodes the most commonly occurring amino acids at the corresponding positions of the solvent accessible residues in known, natural antibodies.

Solvent accessible residues in the CDRs were identified in the antibody variable domain template molecule by analyzing the crystal structure of the template molecule. Humanized antibody 4D5 is efficiently produced and properly folded when produced in a variety of host cells, including bacterial cell culture. The crystal structure for the humanized antibody 4D5 variable region is known and publicly available at [www.rcsb.org](http://www.rcsb.org) (accession code IFVC).

The solvent accessible positions in the CDRs of the light chain and CDR1 and CDR2 of the heavy chain were identified using the Insight II program (Accelrys, San Diego, CA).

CDR residues were also analyzed to determine which positions in the CDRs were highly diverse. Highly diverse positions in the CDR regions for the heavy and light chains were identified by examining the sequences of known, naturally occurring antibodies in the Kabat database. The Kabat database is available at

immuno/bme/nwu/edu. In the Kabat database, there were about 1540 sequences of the human light chain and 3600 sequences for the human heavy chain. The CDR sites were aligned and numbered as described by Kabat (see immuno/bme/nwu/edu). Highly diverse amino acid positions were identified by lining up and ranking the amino acid usage, from most frequently used to less frequently used for each CDR residue. For example, L3-91 (i.e., residue 91 of the light chain CDR3) was found to be Y (tyrosine) in 849 out of 1582 antibody sequences in the Kabat database, and it is the amino acid found most frequently at this position. Next on the list of frequency serine (occurring in 196 sequences), followed by arginine (169 sequences), alanine (118 sequences), glycine (61 sequences), histidine (41 sequences), with the remaining 35 sequences being one of the remaining amino acids. Illustrative diverse sites, with corresponding diversity list of amino acids, are shown in Figure 1 (for the light chain). The highly diverse positions, as well as the most frequent amino acids at those positions, may change over time as more sequences are incorporated into the database.

Amino acid residues found in a particular position that collectively constitute the most frequently occurring amino acids among the known, natural antibody sequences are selected as the basis for library design. The most frequently occurring amino acids were deemed to be those that most commonly found in the top 90% of the list of diverse amino acids (this group of amino acids is referred to herein as “target group of amino acids”). However, as described herein, the percent cutoff for a target group of amino acids can be varied, as described above, according to the circumstances and purpose of the diversity library that is to be achieved.

For humanized antibody 4D5, the positions identified as solvent accessible and highly diverse were:

#### Light Chain

CDR1	28, 29, 30, 31, 32
CDR2	50, 53
CDR3	91, 92, 93, 94, 96

Examples of amino acids that occur at high frequency in natural diversity (i.e., among known, natural antibody sequences) (referred to as “target group” or “natural diversity” in Figure 3), and the designed diversity of amino acids by DNA codons (“Diversity<DNA codon>”) for each of these positions is shown in Figure 3.

Codon sets encoding a specific group of amino acids (Diversity) were designed to include at least a certain percentage of the amino acids in the known, natural sequences (designated as “% covering” in Figure 3). Of the amino acids encoded by a codon set, at least about 40% of the amino acids, more preferably 5 70%, are target amino acids identified for a particular solvent accessible and highly diverse position (designated as “% good” in Figure 3; amino acids encoded by a codon set that are target amino acids are shown in bold in column 3 of Figure 3). However, as described herein, the % good value can be varied according to circumstance and objectives. The codon sets were selected such that they preferably 10 encoded the amino acids with the highest occurrences at a particular position. The number of non-target amino acids coded by a codon set for a particular position was minimized. Effectiveness of codon set selection/design was evaluated in part based on the “% good” value. A high percentage meant very low non-target amino acids; a high value of “% good” was deemed more important than having more target 15 amino acids among the amino acids coded by a particular codon set. Redundancy was included in calculating the “% good” value. For evaluation purposes, the “% covering” value was also calculated. This value represents the percentage of natural diversity covered by the “good” amino acids (of the amino acids encoded by a particular codon set). For example, for L3-91, when codon set KMT is used, the 20 “good” amino acids are YSA, which is 75% of the YSAD amino acids encoded by the codon set. YSA are amino acids that cover 1190 out of 1580 known, natural antibody sequences at this amino acid position.  $1190/1580$  equals 75%, which is the “% covering” value. Thus, in one design using KMT at L3-91, 75% of the library covers 75% of the natural diversity in CDRL3 at position 91.

25 The codon sets were also designed to exclude, when possible, cysteine and stop codons. The presence of cysteine residues tends to cause folding problems and stop codons can decrease the effective library size. In the design of the codon sets, it was also deemed desirable to minimize the number of nontarget amino acids.

The codon sets designed for each solvent accessible and highly diverse 30 residue of humanized antibody 4D5 are shown in Figure 3. At any particular residue, one or more codon sets could be used depending on the target amino acids that were identified. Codon sets *YKG* and *TWT* can each be used to generate diversity at L3-96.

The various codon sets could be used to generate diverse libraries with diversity in one or more CDR regions, including CDRL1, CDRL2 and CDRL3. For example, Figures 5-13 and Figure 24 show various illustrative versions of codon set designs that can be used to generate diversity. Figures 3A and 3B provide a summary of the amino acid coverage of these designs. In general, it is preferable, but not necessary, that the designs narrow the diversity to cover more of the natural diversity and exclude as much as possible the "non-target" amino acids.

### **EXAMPLE 5**

#### **Construction, sorting and analysis of scFv libraries**

Libraries with diversified CDRs were generated using vectors comprising 4D5 variable domains in the scFv or scFv-zip formats in vector pS1607 as described in Example 1. In total, five libraries were generated and the library characteristics were as follows:

Library name	Format	CDR Diversity
ScFv-1	zipper	H1, H2, H3
ScFv-2	Zipper	H1, H2, H3, L3
ScFv-3	Zipper	H3, L3
ScFv-4	No zipper	H1, H2, H3
ScFv-5	No zipper	H1, H2, H3, L3

Libraries were constructed using the method of Kunkel (Kunkel et al., *Methods Enzymol.* (1987), 154, 367-382) with previously described methods (Sidhu et al., *Methods Enzymol.* (2000), 328, 333-363). For each library a "stop template" version of a scFv or scFv-zip display vector was used; in each case, a stop template with TAA stop codons within each of the CDRs to be randomized was used. Mutagenic oligonucleotides with degenerate codons at the positions to be diversified were used to simultaneously introduce CDR diversity and repair the stop codons. For example, for the construction of library scFv-1, three oligonucleotides were simultaneously used to introduce diversity into CDR-H1, CDR-H2, and CDR-H3. Successful incorporation of all the mutagenic oligonucleotides resulted in the introduction of the designed diversity at each position and simultaneously repaired the stop codons, thus generating an open reading frame that encoded either a scFv or

scFv-zip fused to the C-terminal domain of the gene-3 minor coat protein. Residues in each CDR were chosen for diversification based on their solvent accessibility and their level of diversity in the Kabat data base of natural antibodies (as described in Examples 2 and 3). For CDRs H1 and H2, the residues chosen for diversification and the diversity introduced at each position are shown in Figure 24. For CDR-H3, diversity was introduced using an equimolar mixture of four mutagenic oligonucleotides (F59, F63, F64 and F65 in Figure 4).

The mutagenesis reactions were electroporated into *E. coli* SS320 (Sidhu et al., *Methods Enzymol.*(2000), 328, 333-363), and the transformed cells were grown overnight in the presence of M13-VCS helper phage to produce phage particles that encapsulated the phagemid DNA and displayed scFv or scFv-zip fragments on their surfaces. Each library contained greater than  $2 \times 10^{10}$  unique members.

#### *1. Selection of Specific Antibodies from the Naïve Libraries.*

Phage from each library described above were cycled through rounds of binding selection to enrich for clones binding to targets of interest. Three target proteins were analyzed: Her2, IGF-1, and mVEGF. The binding selections were conducted using previously described methods (Sidhu et al., supra).

NUNC 96-well Maxisorp immunoplates were coated overnight at 4°C with capture target (5 ug/mL) and blocked for 2 h with bovine serum albumin (BSA) (Sigma). After overnight growth at 37 °C, phage were concentrated by precipitation with PEG/NaCl and resuspended in PBS, 0.5% BSA, 0.1% Tween 20 (Sigma), as described previously (Sidhu et al., supra). Phage solutions ( $10^{13}$  phage/mL) were added to the coated immunoplates. Following a 2 h incubation to allow for phage binding, the plates were washed 10 times with PBS, 0.05% Tween20. Bound phage were eluted with 0.1 M HCl for 10 min and the eluant was neutralized with 1.0 M Tris base. Eluted phage were amplified in *E. coli* XL1-blue and used for further rounds of selection.

The libraries were subjected to two rounds of selection againsts each target protein (Her-2, IGF-1 or mVEGF), followed by a round of selection (round 2a) against an anti-gD epitope antibody to enrich for clones displaying scFv or scFv-zip (there is a gD epitope in the linker between the light chain and heavy chain regions of the scFv). Following the anti-gD enrichment, each library was selected for a third round against the target protein.

Individual clones from each round of selection were grown in a 96-well format in 500 uL of 2YT broth supplemented with carbenicillin and M13-VCS, and the culture supernatants were used directly in phage ELISAs (Sidhu et al., supra) to detect phage-displayed scFvs that bound to plates coated with target protein. The results for each library against each target protein after three rounds of sorting are shown in Figure 25, and it can be seen that each library produced binders against each target protein.

The three scFv-zip libraries (scFv-1, scFv-2 and scFv-3) were subjected to more detailed analysis. Phage clones from round 3 of selections against IGF-1 or mVEGF were analyzed for specific binding to target by doing phage ELISAs against both IGF-1 and mVEGF. Clones that bound only to the target against which they were selected were classified as specific while those that bound both targets were classified as non-specific. The results are shown in Figure 26 which indicates the percentage of clones from each selection that bound targets (Total) and the percentage of clones that bound only the target against which they were selected (specific). All three libraries produced specific binding clones against target, although library scFv-3 produced considerably fewer specific binders than did libraries scFv-1 and scFv-2.

For library scFv-1, clones were also screened from round 2 of selection. From the IGF-1 selection, 140 out of 960 screened clones (15%) were positive. From the mVEGF selection, 24 out of 1152 screened clones (2%) were positive.

For one scFv library (library scFv-4), several hundred clones from round 3 of the IGF-1 or mVEGF binding selections were screened for specific binders. In this case, the IGF-1 selection yielded 35% specific binders while the mVEGF selection yielded 40% specific binders.

Figure 29 shows the sequences and affinities of some positive binders from scFv and ScFv-zip libraries.

## 2. Sequencing of Antigen Specific Binders

Representatives of the specific binding clones characterized above were sequenced using standard methods. The results are shown in Figure 27.

From the IGF-1-specific binders, a total of 255 clones were sequenced and 192 of these were unique sequences. From the mVEGF-specific binders, 202 clones were sequenced and 86 of these were unique sequences. These results confirmed that the methods of the invention for generating CDR diversity and selecting for



antigen specific binders resulted in a multiplicity of antigen specific antibody variable domains with different sequences.

The complete sequences from about 450 binding clones were analyzed for amino acid diversity at the heavy chain residues that were diversified in the library designs. The results indicated that all the designed substitutions occurred with a good distribution of amino acid type (data not shown).

Analysis of the sequences of the CDR-H3 region indicated that all four different designs included in the naïve libraries (F59, F63, F64 and F65 in Figure 4) were also present in the selected binding clones, as shown in Figure 28. However, the four CDR designs were not equally common among the selected binders, indicating that some CDR designs may be better suited for generating positive binding clones against particular targets. In particular, the design F64 was the most prevalent (52%) while the design F63 was the rarest (5%) (Figure 28).

#### EXAMPLE 6

##### F(ab')<sub>2</sub> Libraries with L3/H3 Diversity

Libraries with diversity in CDRL3 and H3 were generated using the template Fab-zip 4D5 vector pS1607 as described in Example 1. For CDRL3, oligonucleotide F61 (F61: GCA ACT TAT TAC TGT CAG CAA NRT NRT RVM NNK CCT TDK ACG TTC GGA CAG GGT ACC; the underlined nucleotides encoding amino acid residues/positions that were diversified; SEQ ID NO: 30). For CDRH3, oligonucleotides used were designated F59, F63, F64, F65, F66, and F78. (See Figure 4). A pair of L3 and H3 oligonucleotides were used per Kunkle mutagenesis reaction, and libraries were made and amplified in E. coli as described in Example 4. In total, six libraries with different H3 diversity (generated with six different oligonucleotides as described above) were made and combined after amplification for sorting on targets. Sorting was done as in Example 4, except that this library underwent two tracks of sorting: with or without presorting on anti-gD before target sorts. The library was either directly sorted on targets (i.e., with no presort) or first on anti-gD as a presorted library before sorting on targets. After one presort, the library was sorted on targets two times and then on anti-gD once before sorting on targets another time. Library without presorting went through targets twice and then was enriched on anti-gD once and then another time on targets.

The hit rate was significantly better with presorted library sorted against mVEGF or IGF-1. For HER2ECD as targets, both presorting or no presorting worked well. The hit rate after two target sorts and one anti-gD sort was about 1-4%. A final sort on target after anti-gD sort resulted in a >90% hit rate. Hit rate was calculated as specific binders found per 100 clones screened. Specific binding clones were defined as in Example 5.

Positive clones were sequenced for their H3 sequences and IC50 (affinity) analyzed as previously described (Sidhu et al, supra). Figure 29 shows the results of analysis of each clone. Clones were obtained with variable sequences and affinity in the range of sub-micromolar and micro-molar. Most binders came from libraries with *DVK* design in H3. In column 2 of Figure 29, underlined residues represent residues that were fixed in the source library of the clones. Most binding clones came from the library that fixed the Y<sub>100a</sub> position.

The binding epitope of some of the clones was also analyzed by competitive binding ELISA. Target (murine VEGF) was coated on 96-well NUNC-maxisorb plate. Phage clones binding to the target in the presence of blocking reagent which bound to a particular epitope on mVEGF was measured. Two mVEGF receptor fragments were used, Flt-D2 (Wiesmann et al., Cell (1997), 91:695-704) or KDR1-7-igg (Fuh et al., J. Biol. Chem. (1998), 273:11197-11204). The results showed that all analyzed binders bound to a similar epitope as KDR1-7-igg since they competed with each other (Figure 30). Flt-D2 (Domain 2 of Flt-1), which has a smaller epitope on mVEGF, only blocked one clone but not the others (Figure 31).

To demonstrate that the binding phage clones did present Fab polypeptide sequences that could become Fab antibody fragments, we generated Fab protein from some of the clones. Phage constructs from binding clones were transformed into E. Coli strain 27C7 that does not have amber stop suppressors, and the bacteria were grown to produce Fab protein. Figure 32 summarizes the characterization of these clones. Fab protein was successfully generated from clones V2, V5 and V8.

30

### EXAMPLE 7

#### Fab and F(ab')<sub>2</sub> Libraries with H1/H2/H3 Diversity

Libraries were generated as described above. Template construct was pV0116b for Fab or pV0116g for F(ab')<sub>2</sub>. These vectors encode light chain variable domains that change the 4D5 residues at position 30 and 66 to reflect human

consensus sequence (N30S; R66S), both of which had *phoA* promoter and *stII* signal sequences for both light chain and heavy chain. To make Fab H1/H2/H3 libraries, each mutagenesis reaction used oligonucleotides that coded for H1, H2 and H3 diversity. To ensure the incorporation of all three CDRs in the randomization scheme, a stop codon (TAA) was incorporated in each CDR that was intended to be diversified. Only clones that incorporated all three CDR oligonucleotides would have positive display since the stop codons would have been replaced. Oligonucleotides of different diversity were first combined to use as a source to diversify each CDR.

For this experiment, two H1 oligonucleotides, F151 (GCA GCT TCT GGC TTC ACC ATT AVT RRT WMY KMT ATA CAC TGG GTG CGT CAG; SEQ ID NO: 16) and F152 (GCA GCT TCT GGC TTC ACC ATT AVT RRT WMY KGG ATA CAC TGG GTG CGT CAG; SEQ ID NO: 14) (See also Figure 13) were pooled, and for H2, oligonucleotides F153 (AAG GGC CTG GAA TGG GTT GST DGG ATT WMT CCT DMT RRC GGT DMT ACT DAC TAT GCC GAT AGC GTC AAG GGC; SEQ ID NO: 18) and F154 (AAG GGC CTG GAA TGG GTT GST DHT ATT WMT CCT DMT RRC GGT DMT ACT DAC TAT GCC GAT AGC GTC AAG GGC; SEQ ID NO: 19) (See also Figure 13) were pooled.

For H3, a *DVK* pool of oligonucleotides (F165, F166) and *NVT* pool (F134, F136, F137, F138, F142, F155, F156, F157, F158, F160, F160g) were used. Figure 4 shows H3 positions that were subjected to diversification. Two Fab libraries were generated: one with *DVK* H3 pool and one with *NVT* H3 pool. The two libraries were amplified in *E. Coli* before being combined for sorting on the targets.

Mutagenized DNA was used to transform *E. Coli* strain SS320 by electroporation and size of the libraries were in the range of  $10^9$ . Transformed bacterial cells were grown up overnight in the presence of helper phage KO7 to produce displaying phage that could still infect other bacterial cells as described in Example 4.

#### **Sorting on mouse Vascular Endothelial cell growth factor (mVEGF) and human IgG1-Fc (hFc)**

*DVK* and *NVT* libraries were pooled for sorting on the targets. Sorting was performed as with other libraries as described above. The combined library was sorted first on target once, next sorted with anti-gD antibody which could get rid of

the non-displaying clones, and next with two sorts on targets (S3, S4). About 96 clones from S3, S4 were screened. Positive clones were clones that had above background binding to the targets (binders) and not to other non-relevant proteins (i.e., specific binders). For mVEGF as target, S4 provided the highest hit rate for positive specific binders. For human Fc, S3 and S4 provided high rate of specific binders.

Library	mVEGF		hFc	
	Total binders	Specific binders	Total binders	Specific binders
Fab S3	36%	1-2%	88%	83%
Fab S4	91%	72%	99%	90%
F(ab') <sub>2</sub> S3	42%	3-5%	ND	ND
F(ab') <sub>2</sub> S4	73%	72%	ND	ND

ND: Not determined

The DNA sequences of the binders and the binding affinity of the unique binders were analyzed. Examples of sequences and binding affinity of binders are shown in Figure 33. For specific hFc binders, many distinct Fab clones, some of which binding at 40nM, 2uM and >5uM individually were obtained. From the F(ab')<sub>2</sub> library, clones with affinities at 41, 47 and 110 nM were obtained. Additional sequences of VEGF binders are shown in Figure 35.

### **EXAMPLE 8**

#### **Solution Binding Competition ELISA**

To determine a binding affinity for selected anti-Her2 F(ab) and F(ab')<sub>2</sub> phage, competition ELISAs were performed as described below. The solution binding competition assay had been previously shown to correlate with Fab protein affinity K<sub>d</sub> as shown in Figure 46. The solution binding assay was used as an efficient method for identifying the affinity of clones for a target antigen from the library.

First, the phage were propagated and purified. Ten uls of XL-1 bacteria infected with one of the clones for 30 minutes at 37°C was plated on a carbenicillin plate. A colony was picked and grown in 2 mls (2YT and 50ug/ml carbenicillin) at 37°C for 3-4 hours. Helper phage, KO7 or VCS (VCS is a variant of KO7) was added to the culture at a final concentration of 10<sup>10</sup> pfu/ml for another 1 hour at

37°C. Twenty mls of media (2YT/CRAP 50:50 with 50ug/ml carbenicillin was added to the culture for growth overnight at 37°C. The phage was purified as described previously.

Second, the concentration of purified phage that would be optimal for use in the following competition ELISA assay was determined (i.e., approximately 90% of maximal binding capacity on the coated plate). 96-well Nunc Maxisorp plates were coated with Her-2 extracellular domain( 2 ug/ml in PBS) at 4°C overnight or at room temperature for 2 hours. The wells were blocked by adding 65ul 1% BSA for 30 minutes followed by 40ul 1% Tween20 for another 30 minutes. Next, the wells were washed with PBS - 0.05% Tween20 5 times. Various dilutions of F(ab) or F(ab')<sub>2</sub> phage down to 0.1 O.D./ml in ELISA buffer (PBS - 0.1%BSA and 0.05% Tween20) were added to the wells for 15 minutes at room temperature. The wells were then washed with PBS - 0.05% Tween20 at least three times. 75ul of HRP-conjugated anti-M13 antibody (Amersham, 1/5000 dilution with ELISA buffer) per well was added and incubated at room temperature for 30 minutes. The wells were washed again with PBS - 0.05% Tween20 at least five times. Next, 100ul/well of a 1:1 ratio of 3,3',5,5'-tetramethylbenzidine (TMB) Peroxidase substrate and Peroxidase Solution B (H<sub>2</sub>O<sub>2</sub>) ((Kirkegaard-Perry Laboratories (Gaithersburg, MD)) was added to the well and incubated for 5 minutes at room temperature. The reaction was stopped by adding 100ul 1M Phosphoric Acid (H<sub>3</sub>PO<sub>4</sub>) ((Kirkegaard-Perry Laboratories (Gaithersburg, MD)) to each well. The optical density of the color in each well was determined using a standard ELISA plate reader at 450 nm. The dilutions of phage were plotted against the O.D. readings.

Third, a competition ELISA was performed. 96-well Nunc Maxisorp plates were coated with human Her-2 ECD (2ug/ml in PBS) at 4°C overnight or at room temperature for 2 hours. The wells were blocked by adding 65ul 1% BSA for 30 minutes followed by 40ul 1% Tween20 for another 30 minutes. The wells were washed with PBS - 0.05% Tween20 5 times. Based on the binding assay above, 50ul of the dilution of phage that resulted in about 90% of maximum binding to the coated plate was incubated with 50ul of various concentrations of human Her-2ECD (0.1 to 500nM) in ELISA buffer solution for 1 hour at room temperature in a well. The unbound phage was assayed by transferring 75ul of the well mixture to second 96-well plate pre-coated with human Her-2ECD and incubating at room temperature for 15 minutes. The wells of the second plate were washed with PBS -

0.5% Tween20 at least three times. 75ul of HRP-conjugated anti-M13 antibody (1/5000 dilution with ELISA buffer) per well was added and incubated at room temperature for 30 minutes. The wells were washed again with PBS - 0.05% Tween20 at least five times. Next, 100ul/well of a 1:1 ratio of 3,3',5,5'-tetramethylbenzidine (TMB) Peroxidase substrate and Peroxidase Solution B (H<sub>2</sub>O<sub>2</sub>) ((Kirkegaard-Perry Laboratories (Gaithersburg, MD))) was added to the well and incubated for 5 minutes at room temperature. The reaction was stopped by adding 100ul 1M Phosphoric Acid (H<sub>3</sub>PO<sub>4</sub>) ((Kirkegaard-Perry Laboratories (Gaithersburg, MD))) to each well. The optical density of the color in each well was determined using a standard ELISA plate reader at 450 nm. The concentrations of competitor were plotted against the O.D. readings. The IC<sub>50</sub>, the concentration of Her-2 ECD that inhibits 50% of the F(ab)-phage or F(ab')<sub>2</sub>-phage, represents the affinity. See also Figure 19.

15

### EXAMPLE 9

A combination of different sorting and screening methods can be used for any of the libraries generated as described herein. Assays utilizing target bound to a solid and solution phase assays may be utilized as described below.

#### Selection for Affinity

20

A combination of sorting methods and high throughput affinity screening assays has been shown effective to select binders with high affinity from a library of either monovalent (Fab) or multivalent F(ab')<sub>2</sub> polypeptides. (Figure 45) Different sorting methods can be used to combine with the screening assay as means to find the high affinity clones. Described below is a method of solution sorting method and a high throughput affinity screening assay.

25

For the first round of sorting, the usual plate-based selection/sorting is preferred because it is more efficient in capturing binding clones. (See also Figure 44.) Add 100ul/well library of phage 1-3 OD (270 nM) in PBS/BSA buffer on target coated Maxisorb wells at room temperature for 1 hour. Wash plate with PBS/0.05% tween20 about five times. Elute with 0.1N HCl for 20 min. at room temperature. Titer and propagate from 4 wells. The washing of the plates is low stringency in order to capture the most binders with a wide range of affinities.

30

For solution sorting, biotinylated target antigen can be used. (See also Figure 45.) To biotinylate the target protein, target protein should preferably be in

amine-free buffer (for e.g., no Tris, no Glycine or any other primary amine containing buffer or free amino acids), preferably at pH higher than 7.0 and protein is preferably > 0.5mg/ml concentration (eg. PBS). Buffer exchange can be done with NAP-5 (Amersham Pharmacia Biotech) column if needed. Stock NHS-Biotin reagent (Pierce Biotechnology) in PBS (100X) is preferably prepared fresh before use. Add in about 3:1 molar ratio to target protein and incubate at room temperature for 30 min. to 1 hour. Add Tris pH7.5 or ethylamine to 100mM to quench the unreacted NHS for 30 min. Buffer exchange with NAP-5 can be used to remove the free biotin reagent. This is not necessary in most cases since there is very low amount of remaining biotin and the concentration of protein can be calculated from dilution after biotinylation. Biotinylated protein should be tested, if possible, for the ability to bind to natural binding partner, e.g. receptor and/or antibody, to make sure biotinylation did not disrupt the function.

Coat plates with 2-5ug/ml neutravidin (Pierce Biotechnology) in PBS 100ul/well 4°C or room temperature for 2 hours. Block the plate with Superblock (Pierce) in PBS for 30 min., then, add Tween20 to 0.2% and block for another 30 min.

Incubate 0.5-1 OD phage with appropriate concentration of biotinylated target protein in 120-150ul buffer containing Superblock 0.5% and 0.1% tween20 for 0.5-1 hour. Dilute 5-10X with binding buffer and apply 100ul/well to neutravidin coated wells to allow capture of biotinylated target bound with phage for 5 min at room temperature with gentle shaking. Wash plate with PBS/tween20 multiple times, for e.g. eight times. For determination of background binding, phage not incubated with biotinylated target antigen is also captured on neutravidin-coated plate. Another possible control is based on biotinylated target antigen mixed with phage captured in a well not coated with neutravidin. Bound phage are eluted with 0.1N HCl for 20 min, neutralized and titered and propagated to next round.

The concentration of biotinylated reagent to use depends on situation. In one instance, using 100-250nM target concentration is equivalent to plate sorting in terms of stringency. For example, to improve affinity of a 100nM binder, it is good to start with 20nM as first solution sort and progress to 5 and 1nM at the second sort. Multiple concentrations should be included. The concentration that provides for enrichment should be used with the screening assay. For the third sort, adding excess of unbiotinylated target as competitive sorting (described below) may be

called for. When low concentration (e.g. < 2nM) of biotinylated target is used, 5X instead of 10X dilution before capture is preferred. Input phage may decrease to 0.1 OD in later round of sorting which will further increase the selection pressure.

Competitive sorting can be done to increase the pressure of selection. After  
5 the 30 min. - 1 hour incubation of phage and biotinylated targets (described above), before dilution for capturing, 1000 fold excess of unbiotinylated target may be added and incubated for different length of time at different temperature. Longer time and higher temperatures (e.g., 37°C vs room temperature) increase the pressure of selection. For example, to improve affinity from a 1 nM anti-VEGF binder: In the  
10 first round of solution sorting, using 1 nM biotinylated target to select. Before dilution for capturing, adding 1 uM unbiotinylated target at room temperature for 15 min. to compete off high off-rate binders. In the following rounds of solution sorting, using 0.1 nM biotinylated target to select tighter binders, and before dilution for capturing, adding 100nM unbiotinylated target at 37°C for 30 min. or, more  
15 stringently, 2 hours to select for the low off-rate binders.

#### High throughput affinity screening assay:

A schematic of this assay is shown in Figure 47. Colonies (freshly grown) were picked and grown in 96 well plate (150ul/well) or rack (300ul/tube) overnight  
20 at 37°C in 2YT/CRAP (1:1) with 50ug/ml carbenicillin and 1n/ml K07. After growth, the colonies were spun down to obtain the phage supernatant.

The phage supernatant was diluted 1:6-10 if grown from plate or 1:3-5 if grown from rack in ELISA binding buffer (PBS, 0.5%BSA, 0.05% Tween20) with or without target antigen in 150 ul total volume and incubated for 1 hour at room  
25 temperature. Final concentration of target in this binding experiment depends on expected/desired the affinity. For screening for sub-nM affinity binders, 10-25nM were used. To screen for 1-100 nM binders, a 100-150nM target concentration is preferred.

Plates were coated with 5ug/ml of target antigen overnight or 2 hours at  
30 room temperature and blocked as described above. About 70-100 ul of phage was transferred with or without target antigen to the coated plate, transferring sample (with or without target antigen) into side by side wells simultaneously. The plates were shaken gently for 10-15 minutes to allow the capture of unbound phage to plate. The plates were washed quickly six times with washing buffer. HRP-



conjugated anti-M13 antibody in binding buffer (1:5000) was added to the plates and incubated for 30 min., the plates were washed 6 times, and the substrate TMB/H<sub>2</sub>O<sub>2</sub> was added for 5-10 min. and absorbance was measured at 450nm.

5       The % inhibition of binding was calculated by calculating the ratio of OD of samples plus target over samples minus target. The lower the %, the higher the potential affinity of the clones. The graph shows the data from screening about 40 clones. The results show that a great variety of affinities ranging from high affinity (low ratio) to low affinity (high ratio) were present in the 40 clones.

10       All publications (including patents and patent applications) cited herein are hereby incorporated in their entirety by reference.

## WE CLAIM:

1. A polypeptide comprising a variant CDRH3 region that comprises an amino acid sequence:

5  $(X_1)_n - X_2 - X_3 - X_4 - X_5 - X_6$

wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or is tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;

$X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*, *DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine, phenylalanine, serine, alanine, glycine, leucine, or tryptophan;

$X_3$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is alanine, valine, aspartic acid or glycine;

$X_4$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is methionine;

$X_5$  is aspartic acid, alanine, valine, or glycine; and

$X_6$  is tyrosine or valine.

2. The polypeptide of claim 1, wherein the polypeptide is a heavy chain antibody variable domain.

3. The antibody variable domain of claim 2, wherein  $X_3$  is alanine,  $X_4$  is methionine,  $X_5$  is aspartic acid and  $X_6$  is tyrosine.

4. The antibody variable domain of claim 2, wherein  $X_2$  is tyrosine.

5. The antibody variable domain of claim 2, wherein  $X_2$  is leucine or phenylalanine,  $X_3$  and  $X_4$  are missing,  $X_5$  is aspartic acid and  $X_6$  is tyrosine.

6. The antibody variable domain of claim 3, wherein  $n = 6$ .

7. The antibody variable domain of claim 5, wherein  $n = 6$ .

8. The antibody variable domain of claim 2, wherein  $n$  is 6, 7, or 8.

9. The antibody variable domain of claim 2, wherein  $X_1$  corresponds to amino acid position 95 and  $n = 6$ ,  $X_2$  corresponds to amino acid position 100a, and  $X_3$  corresponds to amino acid position 100b in CDRH3 of antibody 4D5.

5

10. A nucleic acid comprising a polynucleotide molecule that encodes the polypeptide of any of claims 1 to 9.

11. A vector that comprises the nucleic acid of claim 10.

10

12. The vector according to claim 11 that is a replicable expression vector.

13. The vector according to claim 12, wherein the vector has a promoter region linked to the polypeptide selected from the group consisting of the lac Z promoter system, the alkaline phosphatase pho A promoter (Ap), the bacteriophage  $\lambda_{PL}$  promoter (a temperature sensitive promoter), the tac promoter, the tryptophan promoter, and the bacteriophage T7 promoter.

20

14. A virus comprising a polypeptide of any of claims 1 to 9 displayed on its surface.

15. A library comprising a plurality of at least  $1 \times 10^8$  distinct polypeptide sequences of any of claims 1 to 9.

25

16. A host cell comprising the vector according to claim 12.

17. The polypeptide of any of claims 1 to 9, further comprising at least one, two, three, four or five, or all variant CDRs selected from the group consisting of CDRH1, CDRH2, CDRL1, CDRL2 or CDRL3, wherein at least one CDR has a variant amino acid in at least one solvent accessible and highly diverse amino acid position, wherein the variant amino acid is encoded by a nonrandom codon set, and

30

wherein at least 70% of the amino acids encoded by the nonrandom set are target amino acids for that position in known antibody variable domains.

18. The polypeptide of claim 17, wherein amino acids encoded by the nonrandom codon set comprise amino acids found at the corresponding position in at least 50% of known antibody variable domains.

19. The polypeptide of any of claims 1 to 9 and 17-18, wherein the variant CDRs are CDRH1 or CDRH2 or both.

10

20. The polypeptide of claim 19, wherein in the variant CDRH3,  $X_1$  corresponds to amino acid 95 and  $n = 6$ ,  $X_2$  corresponds to amino acid 100a,  $X_3$  corresponds to amino acid 100b, and  $X_6$  corresponds to amino acid 102 in CDRH3 of antibody 4D5.

15

21. The polypeptide of claim 20, wherein in CDRH3,  $X_3$  is alanine,  $X_4$  is methionine,  $X_5$  is aspartic acid and  $X_6$  is tyrosine.

22. The polypeptide of claim 20, wherein in CDRH3,  $X_2$  is phenylalanine or leucine,  $X_3$  and  $X_4$  are missing,  $X_5$  is aspartic acid and  $X_6$  is tyrosine.

20

23. The polypeptide of claim 19, wherein CDRH1 comprises a variant amino acid at in at least one, two, three, four or all of amino acid positions 28, 30, 31, 32 and 33; and CDRH2 comprises a variant amino acid in at least one, two, three, four, five or all of amino acid positions 50, 52, 53, 54, 56 and 58.

25

24. The polypeptide according to claim 19, wherein each variant amino acid position in CDRH1 and CDRH2 has a variant amino acid wherein

- 1) in CDRH1,
  - a) the variant amino acid at position 28 is encoded by *AVT*, *WCC* or is threonine;
  - b) the variant amino acid at position 30 is encoded by *RVM* or *AVT*;

30

c) the variant amino acid at position 31 is encoded by *RVM, RVT or RRT*;

d) the variant amino acid at position 32 is encoded by codon set *WMY*; and

5 e) the variant amino acid at position 33 is encoded by codon set *KVK, RNT, DMT, KMT or KGG* or the combination of codon sets *KMT and KGG*; and

wherein

2) in CDRH2,

10 a) the variant amino acid at position 50 is encoded by codon set *KDT or DBG* or the combination of codon sets *DGG and DHT*;

b) the variant amino acid at position 52 is encoded by codon set *DHT or DMT*;

15 c) the variant amino acid at position 53 is encoded by codon set *NMT or DMT*;

d) the variant amino acid at position 54 is encoded by codon set *DMK, DMT or RRC*;

20 e) the variant amino acid at position 56 is encoded by codon set *DMK or DMT*; and

f) the variant amino acid at position 58 is encoded by codon set *DMT or DAC*.

25 25. The antibody variable domain according to claim 24, wherein in the variant CDRH3,  $X_1$  corresponds to amino acid position 95 and  $n = 6$ ,  $X_2$  corresponds to amino acid position 100a,  $X_3$  corresponds to amino acid position 100b, and  $X_6$  corresponds to amino acid position 102 in CDRH3 of antibody 4D5.

30 26. A polypeptide comprising at least two antibody variable domains comprising:

a) a heavy chain antibody variable domain of any of claims 1 to 9, and 17-25; and

b) a light chain antibody variable domain comprising a variant CDRL1, CDRL2, CDRL3 or mixtures thereof, wherein

5 i) at least one variant CDRL1, CDRL2 or CDRL3 or mixtures thereof comprises a variant amino acid in at least one solvent accessible and highly diverse amino acid position, wherein the variant amino acid is encoded by a non-random codon set, and wherein at least 70% of the amino acids encoded by the nonrandom codon set are target amino acids for that position in known antibody variable domains.

10 27. The polypeptide of claim 26, wherein  
CDRL1 comprises variant amino acids in one or more amino acid positions 28, 29, 30, 31 and 32;  
CDRL2 comprises a variant amino acid in one or more amino acid positions 50 and 53; and  
CDRL3 comprises a variant amino acid in one or more amino acid  
15 positions 91, 92, 93, 94 and 96.

28. The polypeptide of any of claims 26-27, wherein each variant amino acid position in each CDR has variant amino acid, wherein

20 1) in CDRL1,  
a) the variant amino acid at position 28 is encoded by *RDY*;  
b) the variant amino acid at position 29 is encoded by *RKT* or *RTT*.  
c) the variant amino acid at position 30 is encoded by  
25 *RVW*;  
d) the variant amino acid at position 31 is encoded by codon set *RVW* or *ANW*; and  
e) the variant amino acid at position 32 is encoded by codon set *DHT* or *THT*;  
30 2) CDRL2,  
a) the variant amino acid at position 50 is encoded by codon set *KBG*; and  
b) the variant amino acid at position 53 is encoded by codon set *AVC*;

- 3) in CDRL3,
- a) the variant amino acid at position 91 is encoded by codon set *KMT* or *TMT* or a combination of *TMT* and *SRT*;
  - b) the variant amino acid at position 92 is encoded by codon set *DHT* or *DMC*;
  - c) the variant amino acid at position 93 is encoded by codon *RVT* or *DHT*;
  - d) the variant amino acid at position 94 is encoded by *NHT* or *WHT*; and
  - e) the variant amino acid at position 96 is encoded by codon set *YHT*, *HWT*, *HTT*, *TDK* or combination of codon sets *YKG* and *TWT*.

29. A polypeptide according to claim 28, wherein in the variant CDRH3  
X<sub>1</sub> corresponds to amino acid position 95 and n = 6; X<sub>2</sub> corresponds to amino acid  
position 100a; X<sub>3</sub> corresponds to amino acid position 100b; and X<sub>6</sub> corresponds to  
amino acid position 102 in CDRH3 of antibody 4D5.

30. A polypeptide according to any of claims 1 to 9 and 17 to 29, further  
comprising a dimerization domain linked to C-terminal region of the heavy chain  
antibody variable domain.

31. A polypeptide according to claim 30, wherein the dimerization  
domain comprises a leucine zipper domain or a sequence comprising at least one  
cysteine residue.

32. A polypeptide according to claim 31, wherein the dimerization  
domain comprises a hinge region from an antibody and leucine zipper.

33. A polypeptide according to claim 30, wherein the dimerization  
domain is a single cysteine.

34. A polypeptide comprising at least one, two, three, four, five or all of CDRs selected from the group consisting of CDRL1, CDRL2, CDRL3, CDRH1, CDRH2 and CDRH3, wherein

- 5 (a) CDRL1 comprises a variant amino acid in at least one, two, three, four or all of amino acid positions 28, 29, 30, 31 and 32;
- (b) CDRL2 comprises a variant amino acid in at least one or both of amino acid positions 50 and 53;
- (c) CDRL3 comprises a variant amino acid in at least one, two, three, four or all of amino acid positions 91, 92, 93, 94 and 96;
- 10 (d) CDRH1 comprises a variant amino acid in at least one, two, three, four or all of amino acid positions 28, 30, 31, 32 and 33;
- (e) CDRH2 comprises a variant amino acid in at least one, two, three, four, five or all of amino acid positions 50, 52, 53, 54, 56 and 58; and
- (f) CDRH3 comprises a variant amino acid in at least one, two, 15 three, four, five, six or all of amino acid positions 95, 96, 97, 98, 99, 100, 100a, 100b, 100c, 101 and 102;

wherein the amino acid positions correspond to the Kabat numbering system; and wherein each variant amino acid of (a) to (e) is encoded by a non-random codon set, and wherein at least about 50% up to 90% or all of the amino acids encoded by the non-random codon set are target amino acids for that amino acid position in 20 antibody variable domains; and wherein at least one variant amino acid of (f) is encoded by codon set *NNK*, *NNS*, *DVK*, *XYZ* or *NVT* or mixtures thereof.

35. The polypeptide of claim 34, wherein the polypeptide comprises an 25 antibody heavy chain variable domain or an antibody light chain variable domain or both.

36. A fusion polypeptide comprising:  
a polypeptide according to any of claims 1 to 9 and 17 to 35, wherein 30 the heavy chain variable domain is fused to at least a portion of a viral coat protein.



37. The fusion polypeptide of claim 36, wherein the viral coat protein is selected from the group consisting of protein pIII, major coat protein pVIII, Soc, Hoc, gpD, pv1 and variants thereof.

5 38. The fusion polypeptide of claim 36 further comprising a dimerization domain between the heavy chain variable domain and the viral coat protein.

39. The fusion polypeptide of claim 35 further comprising a light chain variable domain fused to a peptide tag.

10

40. The fusion polypeptide of claim 39, wherein the peptide tag is selected from the group consisting of gD, c-myc, poly-his, fluorescence protein, and B-galactosidase.

15 41. A polypeptide of any of claims 1 to 9 and 17 to 40, further comprising FR1, FR2, FR3 or FR4 for each variable domain from a single antibody template.

42. The polypeptide of claim 41, wherein each of the FR have the  
20 sequence of antibody 4D5 (SEQ ID NO: 1).

43. The polypeptide of claim 42, wherein heavy chain FR residues at one, two, three or all amino acid positions 49, 93, 94 or 97 of the heavy chain and amino acid position 66 the light chain of antibody 4D5 have been altered.

25

44. The polypeptide of claim 36, wherein heavy chain FR at position 49 is alanine or glycine, at position 93 is alanine or serine, position 94 is arginine or lysine or threonine, and position 71 is arginine, valine or alanine.

30 45. A nucleic acid comprising a polynucleotide molecule encoding a polypeptide of any of claims 17-44.

46. A vector that comprises the nucleic acid of claim 45.

47. The vector according to claim 46 that is a replicable expression vector.

48. The vector according to claim 47, wherein the replicable expression vector is M13, f1, fd, Pf3 phage or a derivative thereof, or a lambdoid phage, such as lambda, 21, phi80, phi81, 82, 424, 434, etc., or a derivative thereof.

49. A virus comprising a polypeptide of any of claims 17-44 displayed on its surface.

10

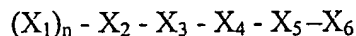
50. A library comprising a plurality of polypeptides of any of claims 17-44, and wherein the library has at least  $1 \times 10^8$  distinct antibody variable domain sequences.

15

51. A host cell comprising the vector of claim 47.

52. A method of generating a composition comprising a plurality of polypeptides comprising:

- a) generating a plurality of polypeptides comprising at least one variant CDR of CDRH1 or CDRH2 or CDRH3 or mixtures thereof wherein
- i) a plurality of polypeptides comprising variant CDRH3 are formed by substituting one or more amino acid positions in an amino acid sequence of



25 wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or is tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;

$X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*, *DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine, phenylalanine, serine, alanine, glycine, leucine, or tryptophan;

30

$X_3$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is alanine, valine, aspartic acid or glycine;

$X_4$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is methionine;

X<sub>5</sub> is aspartic acid , alanine, valine, or glycine;and

X<sub>6</sub> is tyrosine or valine;

- 5                   ii)       forming a plurality of variant CDRH1 or CDRH2 or both comprising at least one variant amino acid in at least one solvent accessible position and highly diverse position, wherein the variant amino acid is encoded by a nonrandom codon set and wherein at least 70% of the amino acids encoded by the nonrandom codon set are target amino acids for that position in known antibody variable domains.

10

53.    A method of claim 52 further comprising:

- 15           i)       generating a plurality of polypeptides comprising a variant CDRL1, CDRL2 or CDRL3 or mixtures thereof, wherein the variant CDRs are formed with at least one variant amino acid in a solvent accessible and highly diverse position; wherein the variant amino acid is encoded by a nonrandom codon set and wherein at least 70% of the amino acids encoded by the nonrandom codon set are target amino acids for that position in known antibody variable domains.

20       54.    A method of selecting for an antigen binding variable domain that binds to a target antigen comprising:

- a)       generating a composition with a plurality of polypeptides of any of claims 1 to 9 and 17 to 44;
- b)       selecting a polypeptide binder that binds to a target antigen
- 25       from the composition;
- c)       isolating the polypeptide binder from the nonbinders;
- e)       identifying high affinity binders from the isolated polypeptide binders.

30       55.    A method of selecting for an antigen binding variable domain that binds to a target antigen from a library of antibody variable domains comprising:

- a)       contacting the library of antibody variable domains of any of claims 1 to 9 and 17 to 44 with a target antigen to form binders;

b) separating the binders from the nonbinders, and eluting the binders from the target antigen and incubating the binders in a solution with decreasing amounts of the target antigen in a concentration from about 0.1 nM to 1000 nM;

5 c) selecting the binders that can bind to the lowest concentration of the target antigen and that have an affinity of about 0.1 nM to 200 nM.

10 56. The method according to claim 55, wherein the target antigen is VEGF, IGF-1, or Her-2.

57. The method according to claim 55, wherein the concentration of target antigen is about 100 to 250 nM.

15 58. The method according to claim 55, wherein the concentration of target antigen is about 25 to 100 nM.

59. A method of selecting for a polypeptide that binds to a target antigen from a library of polypeptides comprising:

20 a) isolating polypeptide binders to a target antigen by contacting a library comprising a plurality of polypeptides of any of claims 1 to 9 and 17 to 44 with an immobilized target antigen under conditions suitable for binding;

25 b) separating the polypeptide binders in the library from nonbinders and eluting the binders from the target antigen to obtain a subpopulation enriched for the binders.; and

c) optionally, repeating steps a-b at least twice, each repetition using the subpopulation of binders obtained from the previous round of selection.

30

60. The method of selecting of claim 59, further comprising:

f) incubating the subpopulation of polypeptide binders with a concentration of labelled target antigen in the range of 0.1 nM to 1000 nM under conditions suitable for binding to form a mixture;

g) contacting the mixture with an immobilized agent that binds to the label on the target antigen;

h) detecting the polypeptide binders bound to labelled target antigens and eluting the polypeptide binders from the labelled target antigen;

5 i) optionally, repeating steps f) to i) at least twice, each repetition using the subpopulation of binders obtained from the previous round of selection and using a lower concentration of labelled target antigen than the previous round.

10 61. The method according to claim 60, further comprising adding an excess of unlabelled target antigen to the mixture and incubating for a period of time sufficient to elute low affinity binders from the labelled target antigen.

15 62. A method of isolating high affinity binders to a target antigen from a library of replicable expression vectors comprising:

a) contacting a library comprising a plurality of polypeptides of any of claims 1-9 and 17-44 with a target antigen in a concentration of at least about 0.1 nM to 1000 nM to isolate polypeptide binders to the target antigen;

20 b) separating the polypeptide binders from the target antigen to obtain a subpopulation enriched for the polypeptide binders; and

c) optionally, repeating steps a-b at least twice, each repetition using the subpopulation of binders obtained from the previous round of selection and using a decreased concentration of target antigen than the previous round to isolate polypeptide binders that bind to lowest concentration of target antigen.

63. An assay for selecting polypeptide binders from a library comprising a plurality of polypeptides of any of claims 1 to 9 and 17 to 44 comprising:

30 a) contacting the library with a concentration of labelled target antigen in a concentration range of 0.1 nM to 1000 nM, under conditions suitable for binding to form a complex of a polypeptide binder and the labelled target antigen;

b) isolating the complexes and separating the polypeptide binders from the labelled target antigen to obtain a subpopulation enriched for the binders;

5 c) optionally, repeating steps a-b at least twice, each time using the subpopulation of binders obtained from the previous round of selection and using a lower concentration of target antigen than the previous round.

64. The method of claim 63, further comprising adding an excess of unlabelled target antigen to the complex of the polypeptide binder and target  
10 antigen.

65. The method of claim 63, wherein the steps are repeated twice and the concentration of target in the first round of selection is about 100 nM to 250 nM, and in the second round of selection is about 25 nM to 100 nM, and in the third round of  
15 selection is about 0.1 nM to 25 nM.

66. A method of screening a library comprising a plurality of polypeptides of any of claims 1 to 9 and 17-44 comprising:

20 a) incubating a first sample of the library with a concentration of a target antigen under conditions suitable for binding of the polypeptides to the target antigen;

b) incubating a second sample of the library without a target antigen;

25 c) contacting each of the first and second sample with immobilized target antigen under conditions suitable for binding of the polypeptide to the immobilized target antigen;

d) detecting the polypeptide bound to immobilized target antigen for each sample;

30 e) determining the affinity of the polypeptide for the target antigen by calculating the ratio of the amounts of bound polypeptide from the first sample over the amount of bound polypeptide from the second sample.

67. A method comprising:

- a) constructing an expression vector comprising a polynucleotide sequence which encodes a light chain variable domain, a heavy chain variable domain or both of a source antibody comprising at least one, two, three, four, five or all CDRs of the source antibody selected from the group consisting of CDR L1, L2, L3, H1, H2 and H3; and
- b) mutating at least one, two, three, four, five or all CDRs of the source antibody at at least one solvent accessible and highly diverse amino acid position using a non random codon set, wherein at least 50% of the amino acids encoded by the nonrandom codon set are target amino acids for that position in naturally occurring antibodies.

68. The method of claim 67, wherein CDRH3 comprises an amino acid sequence:

$(X_1)_n - X_2 - X_3 - X_4 - D - X_5$

and is mutated at at least one amino acid position; wherein the mutations are selected from the group consisting of:

$X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or is tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;

$X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*, *DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine, phenylalanine, serine, alanine, glycine, leucine, or tryptophan;

$X_3$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is alanine, valine, aspartic acid or glycine;

$X_4$  is missing when  $X_2$  is phenylalanine or leucine, or if present, is methionine;

$X_5$  is aspartic acid, alanine, valine, or glycine; and

$X_6$  is tyrosine or valine.

69. The method of claim 68, wherein CDRH1 is mutated at amino acid positions corresponding to amino acid 28, 30, 31, 32 and 33 of antibody 4D5, and CDRH2 is mutated at amino acid positions corresponding to amino acid positions 50, 52, 53, 54, 56 and 58 of antibody 4D5.

70. A method according to claim 69, wherein  $X_1$  corresponds to amino acid position 95 in antibody 4D5 and  $n = 6$ ;  $X_2$  corresponds to amino acid position 100a in antibody 4D5,  $X_3$  corresponds to amino acid position 100b in antibody 4D5,  $X_4$  corresponds to amino acid position 100c in antibody 4D5, and  $X_5$  corresponds to amino acid position 102 in antibody 4D5.

72. A polypeptide comprising a variant CDRH3 region that comprises an amino acid sequence:

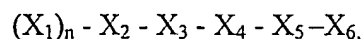


10 wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;

$X_2$  is any naturally occurring amino acid encoded by a codon set of *KSG*, *DVK*, *DSG*, *NVT*, *KSG*, *NNS*, *XYZ*, *NNK* or is tyrosine, glycine, phenylalanine, serine, alanine, leucine, or tryptophan;

15 A is alanine; M is methionine; D is aspartic acid; and Y is tyrosine.

73. A polypeptide comprising a variant CDRH3 region that comprises an amino acid sequence:



20 wherein  $X_1$  is any naturally occurring amino acid encoded by a codon set of *NNK*, *NNS*, *DVK*, *NVT*, *XYZ* or tryptophan or glycine or mixtures thereof, and  $n = 4$  to 14;

$X_2$  is phenylalanine or leucine;

$X_3$  is missing ;

$X_4$  is missing ;

25  $X_5$  is aspartic acid , alanine, valine, or glycine; and

$X_6$  is tyrosine or valine.

74. The polypeptide of claim 73, wherein  $X_2$  is phenylalanine,  $X_5$  is aspartic acid and  $X_6$  is tyrosine.

30

75. The polypeptide of claim 35, wherein position 95 can have a variant amino acid encoded by codon set *DVK*, *NVT*, *NNS*, *XYZ*, *NNK* or is tryptophan; position 96 can be encoded by *DVK*, , *NVT*, *NNS*, *XYZ*, or is glycine or tryptophan; position 97 can be encoded by *DVK*, *NVT*, *NNS*, *XYZ*, or is tryptophan; position 98



can be encoded by *DVK*, *NVT*, *NNS*, *XYZ*, or is tryptophan; position 99 can be encoded by *DVK*, *NVT*, *NNS*, *XYZ*; position 100 can be encoded by *DVK*, *NVT*, *NNS*, *XYZ*, or is tryptophan; position 100a can be encoded by *DVK*, *DSG*, *KSG*, *NVT*, *NNS*, *XYZ*, or can be tyrosine, glycine, serine, alanine, tryptophan, aspartic acid, methionine, phenylalanine, leucine, valine; position 100b can be encoded by *DSG*, *KSG*, *XYZ* or is alanine, tyrosine, glycine, valine, aspartic acid, methionine, or phenylalanine; Position 100c can be encoded by *KSG*, *XYZ*, or is methionine, phenylalanine, leucine, alanine, glycine, valine, tyrosine, aspartic acid; position 101 can be encoded by *KSG*, *XYZ* or is aspartic acid, methionine, alanine, valine, glycine, tyrosine, phenylalanine, leucine; and position 102 can be encoded by *KSG* or *XYZ* or is tyrosine, aspartic acid, methionine, alanine, valine, glycine.

FIG. 1

	S	N	V	D	G	I	T	L	X	
28	511	262	258	186	178	44	39	16	35	
29	1	S	V	G	N	X				
	612	272	254	192	147	70				
30	S	N	K	G	R	Y	T	D	A	X
	849	176	169	86	81	63	29	28	17	45
31	S	N	T	R	I	D	K	G	X	
	676	496	170	47	29	28	25	18	53	
32	Y	N	W	F	S	D	R	X		
	1055	128	97	77	61	40	25	69		
50	G	A	D	W	K	L	E	S	X	
	386	341	294	151	116	91	39	30	82	
53	S	N	T	K	I	R	X			
	545	438	407	41	23	23	58			
91	Y	S	R	A	G	H	X			
	849	196	169	118	61	41	148			
92	Y	G	N	S	D	L	T	H	I	X
	362	356	248	193	114	94	64	43	38	91
93	S	N	Q	T	H	G	D	R	X	
	738	346	117	101	66	51	47	35	112	
94	S	T	W	Y	L	F	A	P	V	I
	386	365	288	172	114	79	46	43	33	N X
96	L	Y	W	F	I	R	P	X		18 40
	264	205	176	140	117	115	46	121		

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[illegible]

**FIG. 2**

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Residue	Natural Diversity	Diversity<DNA codon>	% good	%covering
L1-28	SNVDGI	SNVDGI<RDT>	100%	94%
L1-29	ISVGN	ISVG<RKT>	100%	86%
L1-29		IV<RTT>	100%	56%
L1-30	SNKGRYTDA	SNKGGRTTDAAE<RVW>	92%	93%
L1-31	SNTRIDKG	SNTRDKGGAAE<RVW>	75%	95%
L1-31		SNTRIIRK<ANW>	100%	94%
L1-32	YNWFSDR	YNFSDATIV<DHT>	55%	88%
L1-32		YFS<THT>	100%	77%
L2-50	GADWKLES	GAWLSV<KBG>	83%	67%
L2-53	SNTKIR	SNT<AVC>	100%	90%
L3-91	YSRAGH	YSAD<KMT>	75%	74%
		YS<TMT>	100%	66%
L3-92	YGNSDLTHI	YNSDTIFAV<DHT>	67%	64%
		YNSDTA<DMC>	83%	62%
L3-93	SNQTHGDR	SNTGDA<RVT>	83%	80%
		SNTDYAFIV<DHT>	44%	76%
L3-94	STWYLFAPVI	STYLFAPVINDH<NHT>	75%	78%
		STYFIN<WHT>	83%	43%
L3-96	LYWFIRP	LYFPHS<YHT>	67%	52%
		LYFIHN<HWT>	67%	58%
		LFI<HTT>	100%	42%
		LLWR<YKG>	100%	47%
		YF<TWT>	100%	29%
H1-28	TS	TSN<AVT>	67%	92%
		TS<WCC>	100%	90%
		T	100%	54%
H1-30	STNRDG	STTNRDGGAAE<RVM>	73%	96%
		STN<AVT>	100%	90%
H1-31	SNGDTRA	SNGGDTTAAE<RVM>	91%	95%
		SNGDTA<RVT>	100%	83%
		SNGD<RRT>	100%	82%
H1-32	YSNGFA	YSNT<WMY>	75%	81%
H1-33	AYWGSDTNV	AAYWGGSSDCE* <KVK>	75%	87%
		AGSDTNVI<RNT>	87%	58%
		AYSNTN<DMT>	100%	62%
		AYSD <KMT>	100%	56%
		WG <KGG>	100%	30%
H2-50	RYWVGIEASNL	YWVVGELCDF* <KDK>	67%	49%
		RWVGASLMT<DBG>	78%	59%
		RWG<DGG>	100%	35%
		YVIASNDFT<DHT>	67%	45%
H2-52	SYNKIRDT	SYNIDTAFV<DHT>	67%	79%
		SYNDTA<DMT>	83%	77%
H2-53	SDYGHNITW	SDYHNTAP<NMT>	75%	75%
		SDYNNTA<DMT>	83%	66%
H2-54	GSDNKFT	SSDKTTAEY* <DMK>	60%	47%
		SDTNAY<DMT>	67%	47%
		GSDN<RRC>	100%	81%
H2-56	STNDYEGA	SSTTNDYEA* <DMK>	90%	90%
		STNDYA<DMT>	100%	86%
H2-58	YNDRSITH	YNDSTA<DMT>	83%	77%
		YND<DAC>	100%	69%

FIG. 3

FIG. 4A

Oligo	93	94	95	96	97	98	99	100	100a	100b	100c	101	102	lengDiversity	
F59	S	R	W	G	G	DVK	DVK	F	Y	A	M	D	Y	11 1.90E+06	
F63	S	R	W	G	DVK	DVK	DVK	DVK	DVK	A	M	D	Y	11 6.00E+08	
F64	S	R	DVK	DVK	DVK	DVK	DVK	NNK	Y	A	M	D	Y	11 6.00E+07	
F65	S	R	DVK	DVK	DVK	DVK	DVK	DVK	Y	A	M	D	Y	12 1.10E+09	
F59	S	R	W	G	DVK	DVK	DVK	DVK	DVK	A	M	D	Y	11 1.90E+06	
F63	S	R	DVK	DVK	DVK	DVK	DVK	DVK	DVK	A	M	D	Y	11 6.00E+08	
F64	S	R	DVK	DVK	DVK	DVK	DVK	NNK	Y	A	M	D	Y	11 6.00E+07	
F65	S	R	NNK	NNK	NNK	NNK	NNK	NNK	Y	A	M	D	Y	11 1.10E+09	
F66	S	R	DVK	DVK	DVK	DVK	DVK	—	—	—	F	D	Y	8 1.90E+06	
F78	S	R	DVK	DVK	DVK	DVK	DVK	—	—	—	—	—	—	—	
F165	A	R/K	DVK	DVK	DVK	DVK	DVK	NNK	Y	A	M	D	Y	11 1.20E+08	
F166	A	R/K	W	NVT	DVK	DVK	DVK	DVK	DSG	A	M	D	Y	11 7.50E+06	
F134	A	R/K/	NVT	NVT	NVT	NVT	NVT	NVT	Y	A	M	D	Y	11 2.90E+06	
F136	A	R/K/	W	NVT	NVT	NVT	NVT	NVT	Y	A	M	D	Y	12 2.90E+06	
F137	A	R/K/	NVT	W	NVT	NVT	NVT	NVT	Y	A	M	D	Y	12 2.90E+06	
F138	A	R/K/	NVT	NVT	NVT	NVT	NVT	NVT	Y	A	M	D	Y	12 2.90E+06	
F142	A	R/K/	NVT	NVT	NVT	NVT	NVT	NVT	Y	A	M	D	Y	12 2.90E+06	
F155	A	R/K	W	NVT	NVT	NVT	NVT	NVT	GIS/AW	A	M	D	Y	12 2.30E+07	
F156	A	R/K	NVT	W	NVT	NVT	NVT	NVT	GIS/AW	A	M	D	Y	12 2.30E+07	
F157	A	R/K	NVT	NVT	W	NVT	NVT	NVT	GIS/AW	A	M	D	Y	12 2.30E+07	
F158	A	R/K	NVT	NVT	NVT	NVT	NVT	NVT	GIS/AW	A	M	D	Y	12 2.30E+07	
F160	A	R/K	NVT	NVT	NVT	NVT	NVT	NVT	GIS/AW	A	M	D	Y	12 2.30E+07	
F160g	A	R/K	NVT	NVT	NVT	NVT	NVT	NVT	GIS/AW	A	M	D	Y	12 2.30E+07	
F165	A	R/K	DVK	DVK	DVK	DVK	DVK	NNK	Y	A	M	D	Y	11 1.20E+08	
F166	A	R/K	W	NVT	DVK	DVK	DVK	DVK	DSG	A	M	D	Y	11 7.50E+06	
F163a	A	R/K	DVK	DVK	DVK	DVK	DVK	DVK	KSG	A	M	D	Y	11 2.70E+08	
F164a	A	R	DVK	DVK	DVK	DVK	DVK	DVK	Y	A	M	D	Y	12 6.10E+08	
F164b	A	R	DVK	DVK	DVK	DVK	DVK	DVK	DSG	A	M	D	Y	12 3.60E+09	
F165a	A	R	DVK	DVK	DVK	DVK	DVK	DVK	DVK	Y	A	M	D	Y	13 1.10E+10
F165b	A	R	DVK	DVK	DVK	DVK	DVK	DVK	DVK	DSG	A	M	D	Y	13 6.60E+10
F155	A	R/K	W	NVT	NVT	NVT	NVT	NVT	GIS/AW	A	M	D	Y	12 2.30E+07	



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FIG. 4C

Oligo	93	94	95	96	97	98	99	100	100a	100b	100c	101	102	length	Diversity
S	R	R	W	G	G	D	G	F	-	Y	A	M	D	Y	10
F66c	A	R	NNS	NNS	NNS	NNS	NNS			Y	A/GN	M	D	Y	1.00E+08
F66d	A	R	NNS	NNS	NNS	NNS	NNS		KSG	A/GN	M	D	D	Y	4.00E+08
F66e	A	R	NNS	NNS	NNS	NNS			Y	A/GN	M	D	D	Y	3.10E+06
F66f	A	R	NNS	NNS	NNS	NNS			KSG	A/GN	M	D	D	Y	1.20E+07
F66a1	A	R	NNS	NNS	NNS	NNS	NNS	NNS	Y	A/GN	M	D	D	Y	3.20E+09
F66b1	A	R	NNS	NNS	NNS	NNS	NNS	NNS	KSG	A/GN	M	D	D	Y	1.28E+10
F66g	A	R	NNS	NNS	NNS	NNS	NNS	NNS	KSG	A/GN	M	D	D	Y	1.23E+10
F66h	A	R	NNS	NNS	NNS	NNS	NNS	NNS	Y	A/GN	M	D	D	Y	3.28E+12
F66i	A	R	NNS	NNS	NNS	NNS	NNS	NNS	NNS	NNS	Y	A/GN	M	Y	1.31E+13
F66j	A	R	NNS	NNS	NNS	NNS	NNS	NNS	NNS	NNS	KSG	A/GN	M	Y	1.26E+13
F171c	A	R/K	NNK	NNK	NNK	NNK	NNK	-	-	-	F	D	D	Y	3.20E+07
F171d	A	R/K	NNK	NNK	NNK	NNK	NNK	-	-	-	F	D	D	Y	1.02E+09
F171e	A	R/K	NNK	NNK	NNK	NNK	NNK	-	-	-	F	D	D	Y	3.28E+10
F171	A	R/K	NNK	NNK	NNK	NNK	-	-	-	-	F	D	D	Y	1.00E+06
F185	A	R/K	XYZ	XYZ	XYZ	XYZ					F	D/A	Y	7	7
F186	A	R/K	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ			F	D	Y	10	10
F187	A	R/K	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	F	D	Y	11	11
F190	A	R/K	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	Y	A	M	D	Y 14
F190a	A	R/K	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ		Y	AN/G	M	D	Y 13
F190b	A	R/K	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ		KSG	AN/G	M	D	Y 13
F190c	A	R/K	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	KSG	AN/G	M	D	Y 14
F190d	A	R/K	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	Y	AN/G	M	Y 15
F190e	A	R/K	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	XYZ	KSG	AN/G	M	Y 15

MRT RHSN KSG WSAG  
GBT AVG GNT AVGD

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## Light Chain Designed Diversity

Diversity:  $\sim 2.9 \times 10^9$

### CDR-L1: diversity $\sim 7 \times 10^3$

28	29	30	31	32
RDT	RTT	RVW	RVW	DHT
D	I	D	D	A
G	V	E	E	D
I		G	G	F
N		K	K	I
S		N	N	N
V		S	S	S
		T	T	T
		R	R	V
				Y

### CDR-L2: diversity = 18

50	53
KBG	AVC
A	N
G	S
L	T
S	
V	
W	

### CDR-L3: diversity $\sim 2.3 \times 10^4$

91	92	93	94	96
KMT	DHT	DHT	NHT	YHT
A	A	A	A	F
D	D	D	D	H
S	F	F	F	L
Y	I	I	H	P
	N	N	I	S
	S	S	L	Y
	T	T	N	
	V	V	P	
	Y	Y	S	
			T	
			V	
			Y	

**FIG. 5**



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# Light Chain Designed Diversity

Diversity:  $\sim 6.1 \times 10^8$

## CDR-L1: diversity $\sim 3.4 \times 10^3$

28	29	30	31	32
RDT	RTT	RVW	ANW	THT
D	I	D	I	F
G	V	E	K	S
I		G	N	Y
N		K	R	
S		N	S	
V		S	T	
		T		
		V		

## CDR-L2: diversity = 18

50	53
KBG	AVC
A	N
G	S
L	T
S	
V	
W	

## CDR-L3: diversity $\sim 1.0 \times 10^4$

91	92	93	94	96
KMT	DMC	RVT	NHT	YHT
A	A	A	A	F
D	D	D	D	H
S	N	G	F	L
Y	S	N	H	P
	T	S	I	S
	Y	T	L	Y
			N	
			P	
			S	
			T	
			V	
			Y	

FIG. 6

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## Light Chain Designed Diversity

CDR-L3: diversity  $\sim 1.3 \times 10^3$ 

91	92	93	94	96
TMT	DMC	RVT	WHT	HTT
S	A	A	F	F
Y	D	D	I	I
	N	G	N	L
	S	N	S	
	T	S	T	
	Y	T	Y	

**FIG. 7**

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**CDR-L1**

28	29	30	31	32
RDT	RTT	RVW	RVW	DHT
D	I	D	D	A
G	V	E	E	D
I		G	G	F
N		K	K	I
S		N	N	N
V		S	S	S
		T	T	T
		V	V	V
				Y

**CDR-L2**

50	53
DVK	AVM
A	N
G	K
L	R
S	S
V	T2
W	

**CDR-L3**

91	92	93	94	96
NRT	NRT	RVM	NNK	TDK
C	C	A2	A	C
D	D	D	C	F
G	G	E	D	L
H	H	G2	E	W
N	N	K	F	Y
R	R	N	G	*
S	S	R	H	
Y	Y	S	I	
		T2	L	
			M	
			N	
			P	
			Q	
			R	
			etc	
			*	

\*Amber stop codon is encoded by the degenerate codon

**FIG. 8**

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**CDR-H1**

28	30	31	32	33
WCC	RVM	RVM	WMY	RNT
S	A	A	N	A
T	D	D	S	D
	E	E	T	G
	G	G	Y	I
	K	K		N
	N	N		S
	R	R		T
	S	S		V
	T	T		

**CDR-H2**

50	52	54	55	57	59
DBG	DHT	NMY	DMT	DMT	DMT
A	A	A	A	A	A
G	D	D	D	D	D
L	F	H	N	N	N
M	I	N	S	S	S
R	N	P	T	T	T
S	S	S	Y	Y	Y
T	T	T			
V	V	Y			
W	Y				

**CDR-H3**

6-8 "DVK" codons encoding  
11 amino acids (ACDEGKNRSYW)

**FIG. 9**

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**CDR-H1**

28	30	31	32	33
WCC	RVM	RVM	WMY	DMT
S	A	A	N	A
T	D	D	S	D
	E	E	T	N
	G	G	Y	S
	K	K		T
	N	N		Y
	R	R		
	S	S		
	T	T		

**CDR-H2**

50	52	54	55	57	59
DBG	DMT	DMT	RRC	DMT	DMT
A	A	A	D	A	A
G	D	D	G	D	D
L	N	N	N	N	N
M	S	S	S	S	S
R	T	T		T	T
S	Y	Y		Y	Y
T					
V					
W					

**CDR-H3:**

6-8 "DVK" codons encoding

11 amino acids (ACDEGKNRSYW) with 18 codons

or 5-8 "NVT" coding 12 amino acids with 12 codons  
(SYCPHRTNSADG)**FIG. 10**

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**CDR-H1**

28	30	31	32	33
ACC	AVT	RVT	WMY	DMT
T	N	A	N	A
	S	D	S	D
	T	G	T	N
		N	Y	S
		S		T
		T		Y

**CDR-H2**

50	52	54	55	57	59
DBG	DMT	DMT	RRC	DMT	DAC
A	A	A	D	A	D
G	D	D	G	D	N
L	N	N	N	N	Y
M	S	S	S	S	
R	T	T		T	
S	Y	Y		Y	
T					
V					
W					

**CDR-H3**

6-8 "DVK" codons encoding

11 amino acids (ACDEGKNRSYW) with 18 codons

or 5-8 "NVT" coding 12 amino acids with 12 codons  
(SYCPHRTNSADG)**CDR-L3**

91	92	93	94	96
TMT	DMC	RVT	WHT	HTT
S	A	A	F	F
Y	D	D	I	I
	N	G	N	L
	S	N	S	
	T	S	T	
	Y	T	Y	

**FIG. 11**

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**CDR-H1**

28	30	31	32	33
ACC	AVT	RRT	WMY	DMT
T	N	D	N	A
	S	G	S	D
	T	N	T	N
		S	Y	S
				T
				Y

**CDR-H2**

50	52	54	55	57	59
DBG	DMT	DMT	RRC	DMT	DAC
A	A	A	D	A	D
G	D	D	G	D	N
L	N	N	N	N	Y
M	S	S	S	S	
R	T	T		T	
S	Y	Y		Y	
T					
V					
W					

**CDR-H3**

6-8 "NVT" coding 11 amino acids with 12 codons  
 (SYCPHRTNADG) ( $12^6=2.9e6$  -  $12^8=4.2e8$ )

**CDR-L3**

91	92	93	94	96
TMT	DMC	RVT	NHT	HTT
S	A	A	A	F
Y	D	D	D	I
	N	G	F	L
	S	N	H	
	T	S	I	
	Y	T	L	
			N	
			P	
			S	
			T	
			V	
			Y	

**FIG. 12**

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**CDR-H1**

28	30	31	32	33
ACC	AVT	RRT	WMY	KGG/KMT
T	N	D	N	W/A
	S	G	S	G/D
	T	N	T	S
		S	Y	Y

**CDR-H2**

50	52	54	55	57	59
DGG/DHT	DMT	DMT	RRC	DMT	DAC
R / A	A	A	D	A	D
W/D	D	D	G	D	N
G/F	N	N	N	N	Y
I	S	S	S	S	
N	T	T		T	
S	Y	Y		Y	
T					
Y					

**CDR-H3**

6 "NVT" coding 11 amino acids with 12 codons  
 (SYCPHRTNADG) with one W walking through,  
 or "DVK" (SSYCWTTNKSRAADEGG\*), \* is stop codon

**CDR-L3**

91	92	93	94	96
TMT	DMC	RVT	NHT	YKG/TWT
S	A	A	A	L2/F
Y	D	D	D	W/Y
	N	G	F	R/
	S	N	H	
	T	S	I	
	Y	T	L	
			N	
			P	
			S	
			T	
			V	
			Y	

**FIG. 13**



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FIG. 14A

1 GAAATGAGCT GTTGACAAATT AATCATCGGC TCGTATAAAG TGAGCGGATA ACAATTTCAC ACAGGAACA GCCAGTCCGT TTAGGTGTTT  
 CTTTACTCGA CAACTGTTAA TTAGTAGCCG AGCATATTAC ACACCTTAAC ACTCGCCTAT TGTAAAGTG TGTCTTTGT CGGTCAAGCA AATCCACAAA  
 ^P<sub>lac</sub> promoter  
 101 TCACGAGCAC TTCACCAACA AGGACCATAG ATTATGAAAA TAAAAACAGG TGCACGCATC CTCGCATTAT CCGCATTTAA GACGATGATG TTTTCCGCCT  
 AGTGCTCGTG AAGTGGTTGT TCCTGGTATC TAATACTTTT ATTTTGTCC ACGTGGTAG GAGCGTAATA GGCCTAATTG CTGCTACTAC AAAAGGGCGA  
 ^Start male secretion signal  
 201 CGGCTTATGC ATCGGATATC CAGATGACCC AGTCCCGAG CTTCCCTGTCC GCCTCTGTGG GCGATAGGGT CACCATCACC TGCCGTGCGA GTCAGGATGT  
 GCCGNATACG TAGGCTATAG GTCTACTGGG TCAGGGGCTC GAGGACAGG CCGAGACACC CGCTATCCCA GTGGTAGTGG ACGGCACGGT CAGTCCCTACA  
 ^light chain start  
 301 GAATACTGCT GTAGCTGGT ATCAACAGAA ACCAGNAAA GCTCCGAGC TTCTGATTTA CTCGGCATCC TTCTCTACT CTGGAGTCCC TTCTCGCTTC  
 CTTATGACA CATCGGACCA TAGTTGTCTT TGGTCTTTT CGAGGCTTCG AAGACTAAAT GAGCCGTAGG AAGAGATGA GACCTCAGG AGAGCGAAG  
 ^CDR-L2  
 401 TCTGGTAGCC GTTCCGGGAC GGAATTCCT CTGACCATCA GCAGTCTGA GCCGGAAGAC TTGCAACTT ATTACTGTCA GCAACATAT ACTACTCCTC  
 AGACCATCGG CAAGCCCTG CCTAAAGTGA GACTGGTAGT CGTCAGAGCT CGGCTTCTG AAGCGTTGAA TAATGACAGT CGTTGTAATA TGATGAGGAG  
 ^CDR-L3  
 501 CCAGGTTCCG ACAGGTTACC AAGTGGAGA TCAATCCGA TATGCCGATG GGTGATCCGA ACCGTTTCCG CGGTAAGAAC CTGGTTTTC ATTCTGAGAT  
 GGTGCAAGCC TGTCCCATGG TTCCACCTCT AGTTTAGCTT ATACGGCTAC CGACTAGGCT TGGCAAGGC GCCATTCTTG GACCAAAAAG TAAGACTCTA  
 ^linker ^gp-tag heavy chain start  
 601 CTCGAGGTT CAGTGGTGG AGTCTGGCG TGCCCTGGTG CAGCCAGGG GCTCACTCCG TTGTCTCTGT GCAGTCTCTG GCTTCAACAT TAAAGACACC  
 GAGCTCCAA GTCGACCACC TCAGACCGCC ACGGACCAC GTCGGTCCCC CGAGTGAGGC ANACAGGACA CGTCAAGAC CGAAGTTGTA ATTTCTGTGG  
 ^CDR-H1  
 701 TATATACACT GGGTGGTCA GGGCCCGGGT AAGGGCTTGC AATGGTTTAT CCTACGATG GTTATACTAG ATATGCCAT AGCGTCAAGG  
 ATATATGTGA CCCACGCACT CCGGGGCCCA TTCCCGGACC TTACCCNAGG TTCTTAATA GATGCTTAC CAATATGATC TATACGGCTA TCGCAGTTCC  
 ^CDR-H2  
 801 GCCGTTTCAC TATAAGCGCA GACACATCCA AAAACACAGC CTACCTACAA ATGACAGCT TAAGAGCTGA GGACACTGCC GTCTATTAT GTAGCCGCTG  
 CGCAAAAGTG ATATTCCGT CTGTGTAGGT TTTTGTGTGG GATGATGTT TACTTGTGTA ATTCTGACT CCGTGTACCG CAGATAATAA CATCGCGGAC  
 ^CDR-H3  
 901 GGGAGGGGAC GGCCTCTATG CTATGGACTA CTGGGGTCAA GGAACACTAG TCACCGTCTC CAGCAGTGGC GGTGGCTCTG GTTCCGGTGA TTTTGAATTAT  
 CCTTCCCCCTG CGAAGATAC GATACCTGAT GACCCAGTT CCTTGTGATC AGTGGCAGAG GTCTCTACCG CCACCGAGAC CAGGCCACT AAAACTAATA  
 ^start p3 C-terminal domain

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FIG. 14B

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1001 GAAAGATGG CAAACGCTAA TAAGGGGCT ATGACCGAAA ATGCCGATGA AAACGGCTA CAGTCTGACG CTAAAGGCAA ACTTGATTCT GTCGCTACTG
      CTTTCTACC GTTTGCGATT ATTCCCCCGA TACTGGCTTT TACGGCTACT TTGCGCGAT GTCAGACTGC GATTCCGTT TGAACCTAAGA CAGCGATGAC

1101 ATTACGGTC TGCTATCGAT GGTTCATTG GTGACGTTTC CGGCTTGCT AATGTAATG GTGCTACTGG TGAATTTGCT GGTCTTAAT CCCAATGGC
      TAAATGCCACG ACGATAGCTA CCAAGTAAC CACTGCAAG GCCGGAACGA TTACCATTAC CACGATGACC ACTAAACGA CCGAGATTAA GGGTTTACCG

1201 TCAAGTCGGT GACGGTGATA ATTACCTTT AATGAATAAT TTCCGTCAAT ATTTACCTTC CCTCCCTCAA TCGGTTGAAT GTCGCCCTTT TGCTTTAGC
      AGTTCAGCCA CTGCCACTAT TAAAGTGAAA TTACTTATTA AAGCAGTTA TAAATGGAAG GGAGGGAGTT AGCCAACTTA CAGCGGGAAC ACAGAAATCG

1301 GCTGGTAAC CATATGAAT TTCTATTGAT TGTGACAAAA TAAACTTAT CCGTGGTGC TTGCGTTTC TTTTATATGT TGCCACCTTT ATGTATGTAT
      CGACCAATTG GTATACTTAA AAGATAACTA AACTGTTTT ATTGAAATAA GGCACCACAG AAACGCAAG AAATATACA ACGGTGGAAA TACATACATA

1401 TTTCTACGT TGCTAACATA CTGCGTAATA AGGAGTCTTA A
      AAAGATGCAA ACGATTGTAT GAGGCATTAT TCCTCAGAAAT T
                                     ^p3 end

```

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FIG. 15A

1 GAATGAGCT GLTGACAATT AATCATCGGC TCGTATAATG TGTGGAAATG TGAGCGGATA ACAATTTAC ACAGGAACA GCCAGTCCGT TTAGGTGTTT  
 CTTTACTCGA CAACTGTTAA TTAGTAGCGG AGCAATTATC ACACCTTAAC ACTCGCCTAT TGTAAAGTG TGTCTTTGT CGGTCAAGCA AATCCACAAA  
 ^P<sub>lac</sub> promoter  
 101 TCACGAGCAC TTCACCAACA AGGACCATAG ATTATGAAA TAAACACAGG TGACGCATC CTCGCAATTAT CCGCATTAAAC GACGATGATG TTTTCGCCT  
 AGTGTCTGTG AAGTGGTGTG TCCTGGTATC TAATACTTTT ATTTTGTCC ACGTGGTAG GAGCGTAATA GCGTAATTTG CTGTACTATC AAAAGCGGGA  
 ^Start male secretion signal  
 201 CGGCTTATGC ATCCGATATC CAGATGACCC AGTCCCGCAG CTCCTGTGCC GCCTCTGTGG GCGATAGGGT CACCATACCC TGCCGTGCCA GTCAGGATGT  
 GCCGAATACG TAGGCTATAG GTCTACTGGG TCAGGGGCTC GAGGGACACG CGCTATCCCA GTGGTAGTGG ACGCACGGT CAGTCTCTACA  
 ^light chain start ^CDR-L1  
 301 GAATACTGCT GTAGCCTGGT ATCAACAGAA ACCAGAGAAA GCTCCGAGC TTCTGATTTA CTCGGCATCC TTCTCTACT CTGGAGTCCC TTCTCGCTTC  
 CTTATGACGA CATCGGACCA TAGTTGTCTT TGGTCTTTT CGAGGCTTCC AAGACTAAAT GAGCCGTAGG AAGGAGATGA GACCTCAGGG AAGAGCGAAG  
 ^CDR-L2  
 401 TCTGTAGCC GTTCCGGGAC GGATTTCACT CTGACCATCA GCAGTCTGCA GCCCGAAGAC TTCGCACTT ATTACTGTCA GCACATTTAT ACTACTCCTC  
 AGACCATCGG CAAGGCCCTG CCTAAAGTGA GACTGTAGT CGTCAGACGT CGGCTTCTG AAGCGTTGAA TAATGACAGT CGTTGTAATA TGATGAGGAG  
 ^CDR-L3  
 501 CCACGTTCCG ACAGGGTACC AAGGTGGAGA TCAAAATCGA TATGCCGATG GCTGATCCGA ACCGTTTCCG CGGTAAAGAAC CTGGTTTTTC ATTCTGAGAT  
 GGTGCAAGCC TGTCCCATGG TTCCACCTCT AGTTAGCCT ATACGGCTAC CGACTAGGCT TGGCAAGGC GCCATTCTTG GACCAAAAG TAAGACTCTA  
 ^linker ^gp-tag heavy chain start  
 601 CTCCGAGGTT CAGCTGGTGG AGTCTGGCGG TGGCCTGGTG CAGCCAGGGG GCTCACTCCG TTGTCTCTGT GCAGCTTCTG GCTTCAACAT TAAAGACACC  
 GAGGCTCCAA GTCGACCACC TCAGACCGCC ACCGACCCAC GTCGGTCCCC CGAGTGAGGC AAACAGGACA CGTCGAAGAC CGAAGTTGTA ATTCTGTGG  
 ^CDR-H1  
 701 TATATACACT GGGTGCGTCA GGCCCGGGT AAGGGCTGG AATGGGTTGC AAGGATTTAT CCTACGAATG GTTATACTAG ATATGCCGAT AGCGTCAAGG  
 ATATATGTGA CCCACGCAGT CCGGGGCCCA TTCCCGGACC TTACCCCAAG TTCTTAATA GGATGCTTAC CAATATGATC TATACGGCTA TGGCAGTTCC  
 ^CDR-H2  
 801 GCGGTTTAC TATAAGCGCA GACACATCCA AAAACACAGC CTACCTACAA ATGAACAGCT TAAGAGCTGA GGCACATGCC GTCTATTATT GTAGCCGCTG  
 CCGCAAGTG ATATTCGGT CTGTGTAGT TTTTGTGTG GATGGATGT TACTGTGCA ATTCGACT CCTGTGACGG CAGATAATAA CATCGCGAC  
 ^CDR-H3  
 901 GGGAGGGGAC GGCTTCTATG CTATGGACTA CTGGGTCAG GGAACACTAG TCACGCTTC CAGCATGTC CCGCCGTGCC CAGCACAGA ACTGCTGGG  
 CCTCCCTCG CCGAAGATAC GATACCTGAT GACCCAGTT CCTGTGATC AGTGGCAGAG GTCGGTACG GCGGGCAGGG GTCGTGGTCT TGACGACCCG  
 ^start zipper

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FIG. 15B

```

1001 GCGCGCATGA AACAGCTAGA GGACAAGGTC GAAGAGCTAC TCTCCAAGAA CTACCACCTA GAGAATGAG TGGCAAGACT CAAAAAATT GTCGGGGAGC
      CCGGCGTACT TTGTCGATCT CCTGTCCAG CTCTCGATG AGAGGTTCTT GATGGTGGAT CTCTTACTTC ACCGTTCTGA GTTTTGTGAA CAGCCCCCTCG

1101 GCGGAAAGCT TAGTGGCGGT GGCTCTGGTT CCGGTGATTT TGATTATGAA AAGATGGCAA ACGCTAATAA GGGGGCTATG ACCGAAAATG CCGATGAAAA
      CGCCTTTCGA ATCACCGCCA CCGAGACCAA GGCCACTAAA ACTAATACTT TTCTACCGTT TCGGATTATT CCCCAGATAC TGGCTTTTAC GGTACTTTTT

      ^start p3 C-terminal domain

1201 CCGGCTACAG TCTGACGCTA AAGGCAAACT TGATTCTGTC GCTACTGANT ACGGTGCTGC TATCGATGGT TTCATTGGTG ACGTTTCCGG CCTTGCTAAT
      GCGCGATGTC AGACTGCGAT TTCCGTTTGA ACTAAGACAG CGATGACTAA TGCCACGACG ATAGCTACCA AAGTAACCAC TGCAAAGGCC GGAACGATTA

1301 GGTAAATGGTG CTAATGGTGA TTTTGCTGGC TCTAATTCCC AATGGCTCA AGTCGGTGAC GGTGATAATT CACCTTTAAT GAATAATTTC CGTCAATATT
      CCATTACCAC GATGACCACT AAACGACCG AGATTAAAGG TTTACCAGT TCAGCCACTG CCACTATTAA GTGGAATAATTA CTTATTAAAG GCAGTTATAA

1401 TACCTTCCCT CCTCAATCG GTTGAATGTC GCCCTTTTGT CTTTAGCGCT GGTAACCAT ATGAATTTTC TATTGNTTGT GACAAAATAA ACTTATTCCG
      ATGGAAGGGA GGGAGTTAGC CAACTTACAG CCGGAAACA GAAATC CGA TACTTAAAG ATAACTAACA CTGTTTATT TGAATAAGGC

1501 TGGTGTCTTT GCGTTTCTTT TATATGTTGC CACCTTTATG TATGTATTTT CTACGTTTGC TAACATACTG CGTAATAAGG AGTCTTAA
      ACCACAGAAA CGCAAAAGAA ATATACAACG GTGGAATAC ATACATAAAA GATGCAACG ATGTATGAC GCATTATTCC TCAGAAAT
      ^p3 end

```

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FIG. 16A

1 GAATAGAGCT GTTGACAAAT AATCATCGGC TCGTATATG TGTGAATG TGACGGATA ACAATTAC ACAGAAACA GCCAGTCCGT TTAGGTGTT  
 CTTTACTCGA CAACGTGTA TTAGTAGCCG AGCATAATAC ACACCTTAAC ACTCGCTAT TGTAAAGTG TGTCTTTGT CGGTAGGCA AATCACAAA  
 ^Prac promoter  
 101 TCAGGAGCAC TTCACCAACA AGGACCATAG ATTATGAAA TAAACAGG TGCACGATC CTCGATTAT CCGCATTAAC GACGATGATG TTTTCGCCCT  
 AGTCTCTGTG AAGTGGTGT TCCTGGTATC TAATACTTTT ATTTTGTCC ACGTGGGTAG GAGCGTAATA GCGTAATTG CTGCTACTAC AANAGCGGA  
 ^Start male secretion signal  
 201 CGGCTTATGC ATCGATATC CAGATGACCC AGTCCCGAG CTCCCTGTCC GCTCTGTGG GCGATAGGT CACCATCACC TCGGTGCA GTCAGATGT  
 GCGCAATACG TAGGCTATAG GTCTACTGGG TCAGGGGCTC GAGGACAGG CGGATATCCA CGCTATGCCA GTGGTAGTGG ACGGACGGT CAGTCTTACA  
 ^light chain start  
 301 GATATCTGCT GTAGCTGGT ATCAACAGAA ACCAGGAAA GCTCCGAAG TTCTGATTTA CTGGGATCC TTCTCTACT CTGGAGTCCC TTCTCGCTTC  
 CTTATGACGA CATCGGACCA TAGTTGTCTT TGGTCCCTTT CGAGCTTCG AGACTAAAT GAGCGGTAGG AAGGATGA GACCTCAGG AAGAGCGAAG  
 ^CDR-L2  
 401 TCTGGTAGCC GTTCCGGGAC GGATTTCACT CTGACCATCA GCAGTCTGCA GCGGAGAGC TTCGCACTT ATTACTGTA GCAACATPAT ACTACTCTC  
 AGACCATCGG CAAGGCCCTG CCTAAAGTGA GACTGGTAGT CGTCAGACGT CGGCTTCTG AAGGTTGAA TAATGACAGT CGTTGTAATA TGATGAGGAG  
 ^CDR-L3  
 501 CCAGTTCGG ACAGGGTACC AAGGTGGAGA TCAACGGAAC TGTGGCTGCA CCATCTGTCT TCATCTTCCC GCCATCTGAT GAGCAGTTGA AATCTGGAAC  
 GGTGCAAGCC TGTCCCATGG TTCCACCTCT AGTTTGCTTG ACACCGACGT GGTAGACAGA AGTAGAAGG CGGTAGACTA CTCGTCACT TTAGACCTTG  
 601 TGCCTCTCT GTGTGCTGC TGAATACTT CTATCCAGA GAGGCCAAG TACAGTGAA GGTGATAAC GCCCTCCAT CGGCTAAGT CCAGGAGAGT  
 ACGGAGACAA CACACGGACG ACTTATTGAA GATAGGCTCT CTCCGCTTC ATGTCACTT CCACCTAITS CGGAGGTTA GCCCATTGAG GGTCTCTTCA  
 701 GTCACAGAGC AGGACAGCAA GGACAGCAC TACAGCTCA GCAGCACCTT GACGCTGAGC AAGCAGACT ACGAGAAACA CAAAGTCTAC GCCTGCGAAG  
 CAGTGTCTCG TCCTGTCTT CCTGTCTGG ATGTGAGT CGTGTGGA CTGCGACTCG TTTCTCTGA TGTCTTTGT GTTTCAGATG CGGACGCTTC  
 801 TCACCATCA GGGCTGAGC TCGCCCTGCA CAAAGAGCTT CAACAGGGA GAGTGTGTT CCAGTCCGG TATGGCTGAT CCGAACCGT TCCGGGGTAA  
 AGTGGGTAGT CCCGACTCG AGCGGGCAGT GTTCTCGNA GTTGTCCCT CTCACACCAC GGTGAGGCC ATACCGACTA GGTGTGGCA AGCGCCAT  
 901 GGACTGGCA TAACTGAGG CTGATCTCT ACGCGGAGC CATCTGGCC CTAGTACGA AGTTCAGTA AAAAGGTA CTAGAGGTG AGGTGATTT  
 CCTGGACCT ATTGAGCTC GACTAGGAGA TCGGCTGTC GTAGCACCGG GATCATGCT TCAAGTGCAT TTTTCCCAT TATCTCCAC TCCACTAAAA  
 ^light chain stop  
 1001 ATGAAAAAGA ATATCGCAIT TCTTCTTGA TCTATGTTCTG TTTTCTTCT TGTACAAAC CGGTAGCTG AGATCTCCGA GGTTCAGCTG GTGAGTCTG  
 TACTTTTCT TATAGGTAA AGAAGACGT AGATACAGC AAAAAGATA ACGATGTTG GCGATGCGAC TCTAGAGGT CCAAGTCGAC CACCTCAGAC  
 ^start still secretion signal  
 ^heavy chain start

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FIG. 16B

1101 GCGTGGCCT GGTGAGCCA GGGGGCTCAC TCCGTTTGC CTGTGAGCT TCTGGCTTCA ACATPAAGA CACCTATATA CACTGGGTGC GTGAGSCCCC  
 CGCCACCGA CCACGTGGT CCCCCGAGT AGGCAACAG GACAGTCGA AGACCGAAGT TGTATTTCT GTGATATAT GTGACCCACG CAGTCCGGG  
 ^CDR-H1  
 1201 GGTGAAGGC CTGGAATGG TTGCAAGAT TTATCTACG AATGGTATA CTAGATATGC CGATAGCTC AAGGCCGTT TCACTATAAG CCAGACACA  
 CCCATTCCC GACCTTACCC AAGTTTCTA AATAGGATG TTACCAATAT GATCTATACG GCTATCGCAG TTCCCGCAA AGTGATATTC GGTCTGTGT  
 ^CDR-H2  
 1301 TCCAAAACA CAGCTTACCT ACAATGAAC AGCTTAAGAG CTGAGGACAC TGCGTCTAT TATTGTAGCC GCTGGGAGG GGACGGCTTC TATGCTATGG  
 AGTTTGTGT GTCCGATGA TGTTTACTTG TCGAATCTC GACTCCTGT ACGCCAGATA AATACATCG CGACCCCTCC CCGCCGAAG ATACGATACC  
 ^CDR-H3  
 1401 ACTACTGGG TCAAGGAACC CTGTCAOCC TCTCCTCGG CTCACCAAG GGGCCATCG TCTTCCCCCT GGCAACCTCC TCCAAAGACA CCTCTGGGG  
 TGAATACCC AGTTCTCTGG GACCAGTGC AGAGGAGCG GAGGTGTTT CCGGTAGCC AGAAGGGGA CCGTGGGAG AGTTCTCGT GGAGACCCCC  
 1501 CACAGCGCC CTGGGCTGCC TGTCAAGGA CTACTTCCC GAACCGGTGA CGGTGCTGTG GAACTCAGG GCCCTGACA GCGGGGTGCA CACCTTCCG  
 GTGTCCCGG GACCCGACG ACCAGTTCT GATGAAGGG CTTGGCCACT GCCACAGAC CTTGAGTCCG CGGACTGTG CCGGCACGT GTGGAAGGGC  
 1601 GCTGTCTAC AGTCTCAGG ACTCTACTC CTCAGCAGG TGTGACCGT GCCCTCCAG AGCTTGGCA CCCAGACCTA CATCTGCAAC GTGAATCACA  
 CGACAGGATG TCAGGATGCC TGAGATGAG GAGTCGTCG ACCACTGCA CGGAGGTG TCGAACCCGT GGTCTGTGAT GTAGACGTTG CACTTAGTGT  
 1701 AGCCCAAGCA CACCAAGGTC GACAAAGAG TTGAGCCCA ATCTTGTAC AAACTCAC TCAGTGGCG TGGCTCTGT TCCGGTGATT TTGATTATGA  
 TCGGGTGGT GTGGTCCAG CTGTTCTTC AACTCGGTT TAGAACACTG TTTTGAAGT AGTCACCGC ACCGAGACA AGGCCACTAA NACTAATACT  
 ^start p3 C-terminal domain  
 1801 AAAGATGGCA AACGCTATA AGGGGGCTAT GACCGAAAT GCCGATGAA ACGGCTACA GTCTGAGCT AAAGCAAAC TTGATTCTGT CGTACTGAT  
 TTTCTACCGT TTGCGATTAT TCCCCGATA CTGGCTTTA CCGTACTTT TCCGGATGT CAGACTGGA TTTCGGTTG AACTAGACA GCGATGACTA  
 1901 TACGGTCTG CTATCGATG TTTTATTGT GAGTTTCCG GCCTTGCTAA TGGTAATGT GCTACTGTTG ATTTGCTGG CTCTAATTC CAATGGCTC  
 ATGCCACGAC GATAGCTACC AAAGTAACCA CTGCAAAAGC CGGAACGATT ACCATTACCA CGATGACCAC TAAACGACC GAGATTAAAG GTTTACCGAG  
 2001 AAGTCGGTGA CCGTGATAAT TCACCTTTAA TGAATAATTT CCGTCAATAT TTACCTTCC TCCTCAATC GGTGATGT CGCCCTTTG TCITTAGGCG  
 TTCAGCCACT GCCACTATA AGTGGAAAT ACTTATTAA GGCAGTATA AATGGAAGG AGGAGTTAG CCACTTACA GCGGGAAC AGAATCGCG  
 2101 TGGTAACCA TATGAATTT CTATTGATG TGACAAATA AACTTATTC GTGGTCTTT TGTATGTTG CCACCTTAT GTATGATTT  
 ACCATTGGT ATACTTAAA GATAACTAAC ACTGTTTTAT TGAATAAG CACCACAGAA ACGCAAGAA AATATACAAC GGTGGAATA CATACATAA  
 2201 TCTAGGTTG CTAACATACT GCGTAATAAG GAGTCTTAA  
 AGATGCAAC GATTGTATGA CGCAATTATC CTCAGANT  
 ^end p3

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FIG. 17A

```

1  GAAATGAGCT GTTGACAAATT AATCATCGGC TCGTATAATG TGTGGAATTG TGAGCGGATA ACAATTTCAC ACAGGAACA GCCAGTCCGT TTAGGTGTTT
   CTTTACTCGA CAACTGTTAA TTAGTAGCG AGCATATATAC ACACCTTAAC ACTCGCTAT TGTAAAGTG TGTCTTTGT CGGTACAGCA AATCCACAAA
   ^Ptac promoter

101 TCACGAGCAC TTCACCAACA AGGACCATAG ATTATGAAAA TAAAAACAGG TGCACGCATC CTCGCATTAT CCGCAATTAC GACGATGATG TTTTCGGCCT
   AGTGCCTCGT AAGTGGTTGT TCCTGGTATC TAATACTTTT ATTTTGTCC ACGTGGGTAG GAGCGTAATA GCGTAATTG CTGTACTAC AAAAGGCGGA
   ^Start male secretion signal

201 CGGCTTATGC ATCCGATATC CAGATGACCC AGTCCCGAG CTCCTGTGCC GCCTCTGTGG GCGATAGGGT CACCATCACC TCCCGTGCCA GTCAGGATGT
   GCCGATACG TAGGCTATAG GTCTACTGGG TCAGGGGCTC GAGGACAGG CGGAGACACC CGCTATCCCA GTGGTAGTGG ACGGCACGGT CAGTCTTACA
   ^light chain start ^CDR-L1

301 GAATACTGCT GTAGCTGCT ATCAACAGAA ACCAGGAAAC GCTCCGAAGC TTCTGATTTA CTGGGCATCC TTCTCTACT CTGGAGTCCC TTCTCGCTTC
   CTTATGAGA CATCGGACCA TAGTTGCTTT TGGTCTTTT CGAGCTTGG AAGACTAAAT GAGCCGTAGG AAGGATGA GACCTCAGGG AAGAGCGAAG
   ^CDR-L2

401 TCTGGTAGCC GTTCCGGGAC GGATTTCACT CTGACCATCA GCAGTCTGCA GCCGGAAGAC TTGCGCAACTT ATTACTGTCA GCAACATTAI ACTACTCTTC
   AGACCATCGG CAAGCCCTG CCTAAAGTGA GACTGGTAGT CGTCAGACGT CGGCCCTCTG AAGGTTGAA TAATGACAGT CGTTGTATA TGATGAGGAG
   ^CDR-L3

501 CCAGGTTTGG ACAGGTTACC AAGTGGAGA TCAACGMAAC TGTGGCTGCA CCATCTGTCT TCATCTTCCC GCCATCTGAT GAGCAGTTGA AATCTGGAAC
   GGTGCAAGCC TGTCCCATGG TTCCACCTCT AGTTTGCTTG ACACCGACCT GGTAGACAGA AGTAGAAGGG CGGTAGACTA CTCGTCAACT TTAGACCTTG

601 TGCCTCTGTT GTGTGCTGC TGAATAACTT CTATCCAGA GAGGCCAAG TACAGTGGAA GGTGGATAAC GCCCTCCAAT CGGTTAACTC CCAGGAGAGT
   ACGGAGACAA CACACGGACG ACTTATTGAA GATAGGGTCT CTCGGTTTC ATGTCACCTT CCACCTATTG CGGAGGTTA GCCCATTGAG GGTCTCTCA

701 GTACAGAGC AGACAGCAA GGACAGCAC TACAGCCTCA GCAGCACCT GCAGCTGAGC AAGCAGACT ACGAGAAACA CAAAGTCTAC GCCTGCGAAG
   CAGTGTCTCG TCCTGTGCTT CCTGTGCTGG ATGTGGAGT GTGCTGGGA CTGCGACTCG TTCTCTCTGA TGCTCTTTGT GTTTCAGATG CGGACGCTTC

801 TCACCATCA GGGCTGAGC TCGCCCGTCA CAAAGAGCTT CAACAGGGA GAGTGTGGTG CCAGTCCGG TATGGCTGAT CCGAACCGTT TCCGCGGTAA
   AGTGGTAGT CCCGACTCG AGCGGCGAGT GTTCTCGAA GTTGTCCCT CTCACACCAC GGTGAGGCC ATACCGACTA GGCTTGGCAA AGGCGCAAT

901 GGACTGGA TAACTCGAGG CTGATCTCT ACGCCGAGC CATCTGGCC CTAGTACGCA AGTTCACGTA AAAAGGTA CTAGAGGTTG AGGTGATTTT
   CCTGGACCGT ATTGACTCC GACTAGGAGA TCGCGCCTGC GTAGCACCGG GATCATGGT TCAAGTGCAT TTTTCCCAT TATCTCCAA TCACATAAAA
   ^light chain stop

1001 ATGAAAAA ATATCGCAIT TCTTCTTGA TCTATGTTGG TTTTCTTAT TGTACAAAC GGTACGGTGG AGATCTCCGA GGTTCAGCTG GTGGAGTCTG
   TACTTTTCT TATAGGTAA AGAAGACGT AGATACAGC AAAAAGATA ACGATGTTG CGCATGCGAC TCTAGAGGCT CCAAGTCGAC CACCTCAGAC
   ^start stII secretion signal ^heavy chain start

```

FIG. 17B

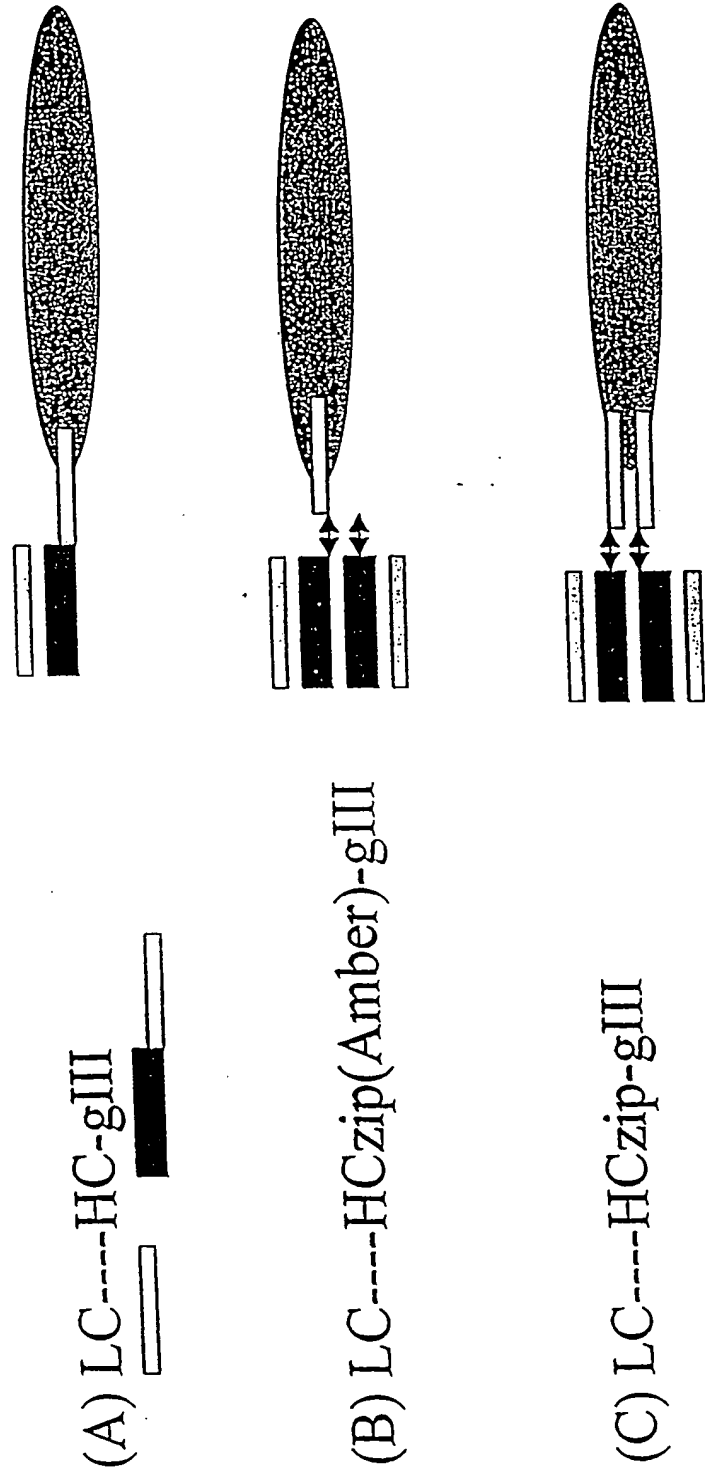
1101 GCGGTGGCCT GGTGAGCCA GGGGGTCAC TCGTTTGTG CTGTGACGT TCTGGCTCA ACATTAAAGA CACCTATATA CACTGGGTGC GTACGGCCCC  
 CGCCACCGGA CCACGTCGGT CCCCCGAGTG AGGCAACAG GACAGTCGA AGACCGAGT TGTAAATTCT GTGGATATAT GTGACCCACG CAGTCCGGGG  
 ^CDR-H1  
 1201 GGGTAAGGGC CTGGAATGGG TTGCAAGGAT TTATCCTACG AATGGTTATA CTAGATATGC CGATAGGGTC AAGGGCCGTT TCACATATAAG CGCAGACACA  
 CCAATTCCCG GACCTTACCC AAGGTTCCCTA AATAGGATGC TTACCAATAT GATCTATACG GCTATGCGAG TTCCCGGCAA AGTGATATTG CGGTCTGTGT  
 ^CDR-H2  
 1301 TCCAAAMACA CAGCTACCT ACAATGAAC AGCTTAAGAG CTGAGGACAC TCCGCTCTAT TATTGTAGCC GCTGGGAGG GGACGGCTTC TATGCTATGG  
 AAGTTTGTGT GTCGGATGGA TGTTTACTTG TCGAATTCTC GACTCTGTG ACGGCAGATA ATAACATCGG CGACCCCTCC CCTGCCGAAG ATACGATACC  
 ^CDR-H3  
 1401 ACTACTGGGG TCAAGGAACC CTGCTACCG TCTCTCGGC CTCCACCAAG GGGCCATCGG TCCTCCCTCT TCCACAGACA CCTCTGGGG  
 TGATGACCCC AGTTCTCTTG GACCAGTGGC AGAGAGCCG GAGGTGGTTC CCGGTAGCC AGAAGGGGA CCGTGGGAGG AGGTTCTCGT GGAGACCCCC  
 1501 CACAGCGGCC CTGGGTGCC TGGTCAAGGA CTACTTCCC GNAACGGTGA CGGTGTGCTG GAACTCAGGC GCCCTGACCA CGGGCTGCA CACCTTCCCG  
 GTGTGCGCGG GACCCGACGG ACCAGTTCTT GATGAAGGGG CTTGGCCACT GCACAGCAC CTTGAGTCCG CGGACTGGT CGCCGACGT GTGGAAGGGC  
 1601 GCTGTCTTAC AGTCTCAGG ACTTACTCC CTCAGCAGG TGGTGACCGT GCCCTCAGC AGCTTGGGCA CCCAGACCTA CATCTGCAC GTGAATCACA  
 CGACAGGATG TCAGGAGTCC TGAGATGAGG GAGTGTGCG ACCACTGGCA CGGGAGGTG TCGAACCCTG GGGTCTGGAT GTAGACGTTG CACTTAGTGT  
 1701 AGCCGAGCNA CACCAAGTTC GACAGAAG TTGAGCCCAA ATCTTGTGAC AAACTCACA CATGCCGCC GTGCCAGCA CCAGAACTGC TGGGCGGCCC  
 TCGGGTCGTT GTGGTCCAG CTGTTCTTTC AACTCGGGT TAGAACACTG TTTGAGTGT GTACGGGGG CACGGTCTGT GGTCTTGACG ACCCGCGGGC  
 ^start zipper  
 1801 CATGAACAG CTAGAGACA AGTCAAGA GCTACTCTCC AAGAACTACC ACCTAGAGAA TGAAGTGGCA AGACTCAAA AACTGTGCG GGAGCGGGA  
 GTACTTTGTC GATCTCTGT TCCAGCTTCT CGATGAGAGG TTCTTGATGG TGGATCTCTT ACTTACCGT TCTGAGTTT TTGAACAGCC CCTCGGCGCT  
 1901 AAGCTTAGTG GCGGTGCTC TGGTTCGGT GATTTTGATT ATGAAGAAT GGCMAACGCT AATAAGGGG CTATGACCGA NAATGCCGAT GAAAACGCGC  
 TTCGAATCAC GCGCACCGAG ACCAAGGCCA CTAAACTAA TACTTTTCTA CCGTTTGGCA TTATTCCCGG GATCTGGCT TTTACGGCTA CTTTTCGCGG  
 ^start p3 C-terminal domain  
 2001 TACAGTCTGA CGCTAAAGC AAACITGATT CTGTGCTAC TGATTACGCT GCTGCTATCG ATGTTTTCAT TGGTGACGTT TCCGGCCTTG CTAATGGTAA  
 ATGTGAGACT GCGATTTCCG TTGAACTAA GACAGCGATG ACTAATGCCA CGACGATAGC TACCAGAGTA ACCACTGCAA AGGCCCGAAC GATTACCAAT  
 2101 TGGTGCTACT GGTGATTTTG CTGGCTCTAA TTCCCAATG GCTCAAGTCG GTGACGGTGA TAATTCACCT TTAATGAATA ATTTCCGTCA ATATTACCT  
 ACCACGATGA CCACTAANAC GACCGAGATT AAGGGTTTAC CGAGTTACG CACTGCCAT ATTAAGTGA AATTACTTAT TAAAGGCAGT TATAAATGGA  
 2201 TCCCTCCCTC AATCGGTGA ATGTGCGCCT TTTGTCTTTA GCGTGTGTAA ACCATATGAA TTTTCTATTG ATTTGACAA AATAAACTTA TTCCGTGGTG  
 AGGGAGGGAG TTAGCCAACT TACAGCGGGA AAACAGAAAT CGCGACCATT TGGTATACTT AAAAGATAAC TAACACTGTT TTATTGGAAT AAGGCACCAC  
 2301 TCTTTGCGTT TCTTTTATAT GTTGCACCT TTATGTATGT ATTTTCTACG TTGTCTAACA TACTGCTAA TAAGGAGTCT TAA  
 AGAAGCGCA AGAAATATA CAACGGTGA AATACATACA TAAAGATGC AAACGATGT ATGACGCAIT ATTCCTCAGA ATT  
 ^end p3



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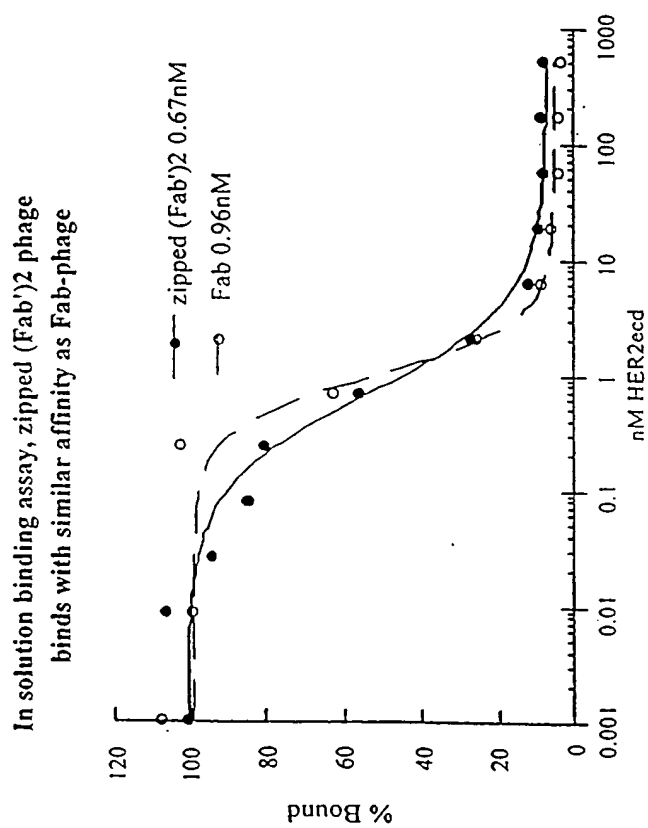
FIG. 18

F(ab) or F(ab)<sub>2</sub>-phage



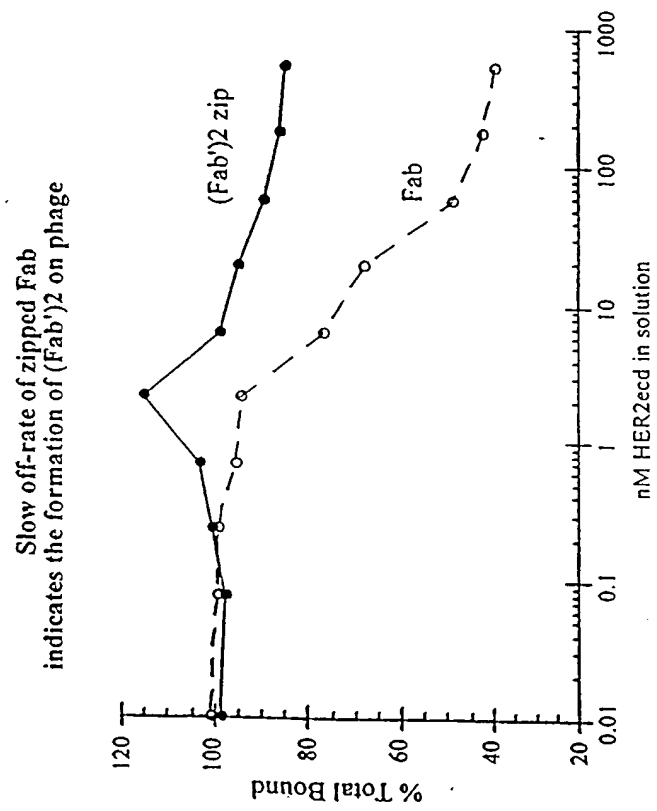
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FIG. 19



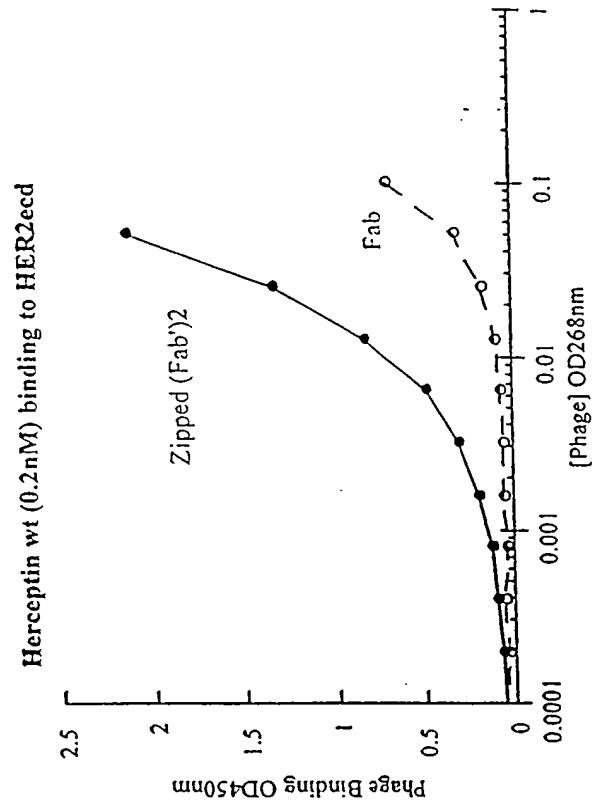
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FIG. 20



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FIG. 21



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FIG. 22

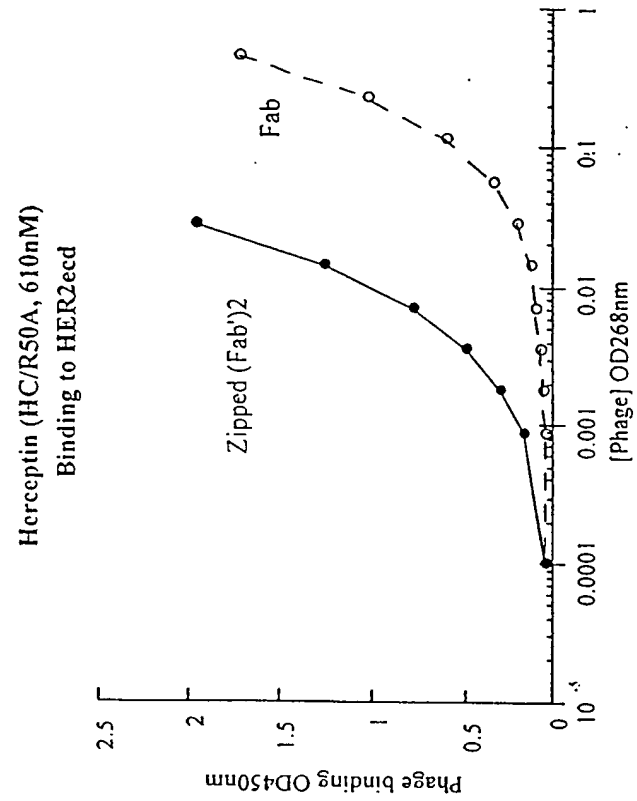
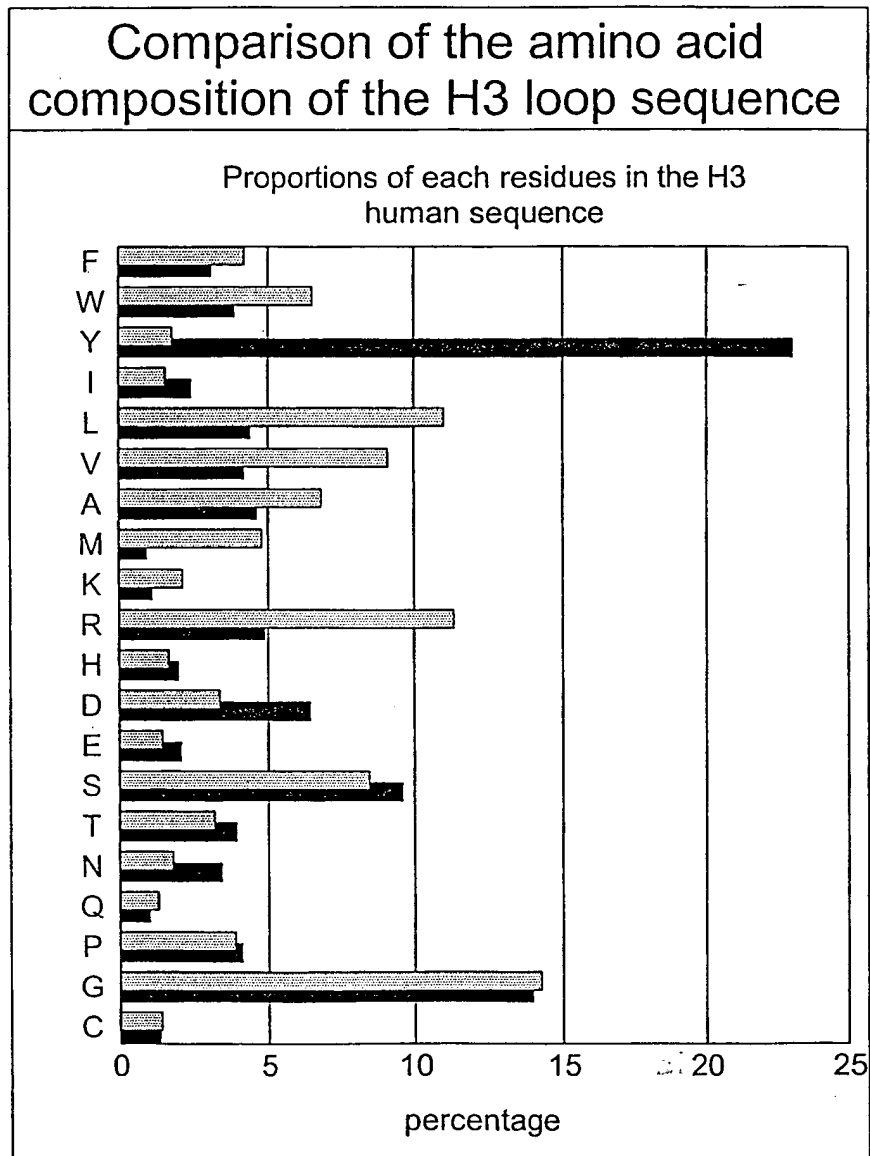


FIG.23



Aliphatic hydrophobic residues occur more frequently in NNK synthetic library than in natural sequences.

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**CDR-H1:**

28	30	31	32	33
AVT	RVM	RVM	WMY	KVK
N	A2	A2	N	A2
S	D	D	S	C
T	E	E	T	D
	G2	G2	Y	E
	K	K		G2
	N	N		S2
	R	R		Y
	S	S		W
	T2	T2		*

**CDR-H2:**

50	52	53	54	56	58
KDK	DMT	NMY	DMK	DMK	DMT
C	A	A	A2	A2	A
D	D	D	D	D	D
E	N	H	E	E	N
F	S	N	K	K	S
G2	T	P	N	N	T
L	Y	S	S2	S2	Y
V2		T	T2	T2	
W		Y	Y	Y	
Y			*	*	
*					

\*Amber (TAG) stop codon is encoded by the degenerate codon

**CDR-H3:**

6-8 "DVK" codons (18) encoding  
12 amino acids (ACDEGKNRSTYW) and stop (\*)

**FIG. 24**

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## ScFv Library Sorting Results

Library	Binders		
	Her2	IGF	VEGF
scFv-1 (H1/H2/H3)Zip	100%	100%	63%
ScFv-2 (L3 /H1/H2/H3)Zip	50%	63%	25%
scFv-3 (L3/H3)Zip	88%	88%	88%
scFv-4 (H1/H2/H3)	38%	50%	63%
scFv-5 (L3 /H1/H2/H3)	25%	13%	25%

FIG. 25



## Detailed Analysis of scFv Zipper Libraries

### Binding clones

Library	IGF		VEGF	
	Total	Specific	Total	Specific
scFv-1	91%	67%	79%	70%
scFv-2	84%	54%	52%	22%
scFv-3	88%	8%	91%	4%

FIG. 26

## Summary of Sequencing Results

Library	Round	Sequences	
		Total	Unique
anti-IGF			
scFv-1	2	72	65
scFv-1	3	95	79
scFv-4	3	88	48
Sum		255	192
anti-VEGF			
scFv-1	2	24	22
scFv-1	3	87	45
scFv-4	3	91	19
Sum		202	86

FIG. 27

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## CDR-H3 Usage in Binding Clones

	95	96	97	98	99	100	100a
4D5	W	G	G	D	G	F	Y
F59	W	G	X	X	X	X	X
F63	X	X	X	X	X	X	X
F64	X	X	X	X	X	X	Y
F65	X	X	X	X	X	X	Y

Percentage of each CDR-H3 in binders

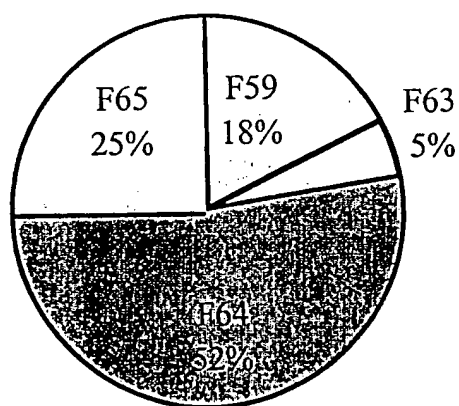


FIG. 28

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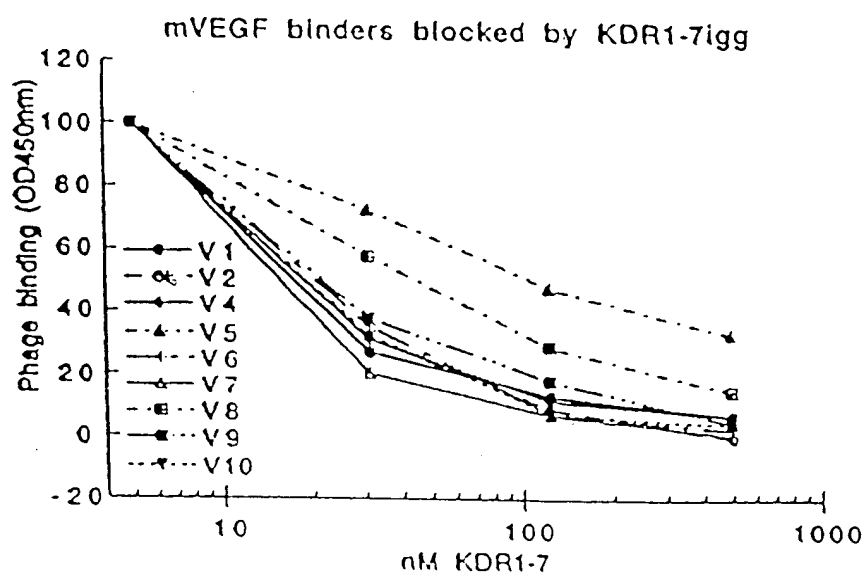
## Binders from L3/H3 library, sort 2 (1-4% hit rate)

H3 Sequences of IGF1 binders (3/8)				
	Sequences	# clones	Source Oligo	IC50 (uM)
I1	<u>SR</u> WKYATR <u>YAM</u>	1	(DVK)5(NNK)1	40
I2	<u>SR</u> SRGWWTA <u>AM</u>	1	(DVK)7	0.3
I3	<u>SR</u> ASRDWYG <u>AM</u>	1	(DVK)7	15
H3 sequences of mVEGF binders (10/25)				
V1	<u>SR</u> NAWA <u>F</u>	6	(DVK)5	5.0
V2	<u>SR</u> NLSENS <u>YAM</u>	1	(NNK)6	0.2
V5	<u>SR</u> AGWAGW <u>YAM</u>	1	(DVK)5(NNK)1	0.6
V8	<u>SR</u> AAKAGW <u>YAM</u>	1	(DVK)5(NNK)1	4.7
V10	<u>SR</u> SDGRDSA <u>YAM</u>	1	(DVK)6(NNK)1	6.0

FIG. 29

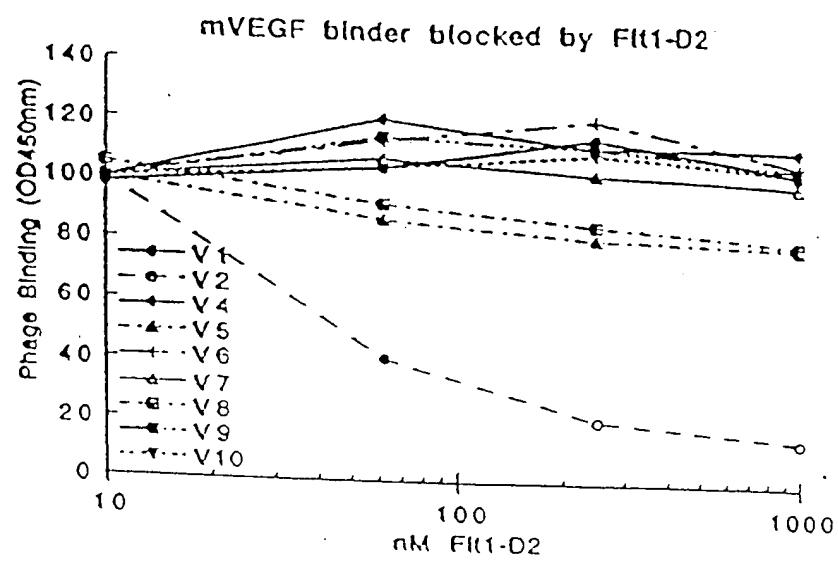
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FIG. 30



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FIG. 31



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## Further Characterization of the mVEGF binders

	H3 seq	IC50 (uM)	Blocking reagent			Fab Protein
			Flt-D2	KDR	Y317	
V1	SR NAWA F	5.0	-	+	+	-
V2	SR NLSENS YAM	0.2	+	+	+	+
V5	SR AGWAW YAM	0.6	-	+/-	+/-	+
V8	SR AAKAGW YAM	4.7	-	+/-	+/-	+

FIG. 32

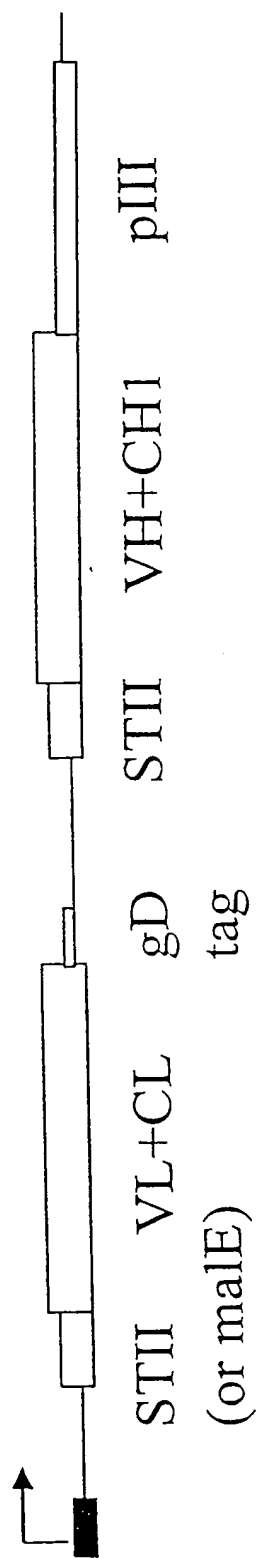




# Phagemid construct

A. Vector for Fab-pIII display

AP promoter (or Ptac promoter)



B. Vector for Fab'2-pIII display

AP promoter (or Ptac promoter)

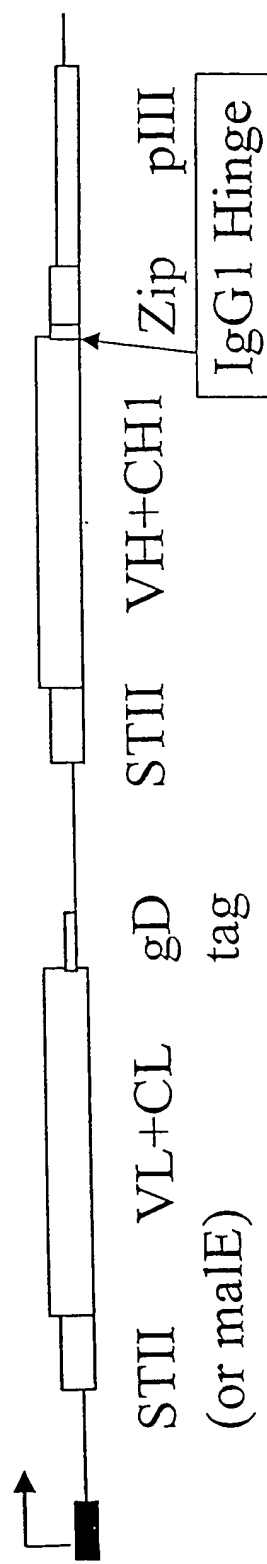
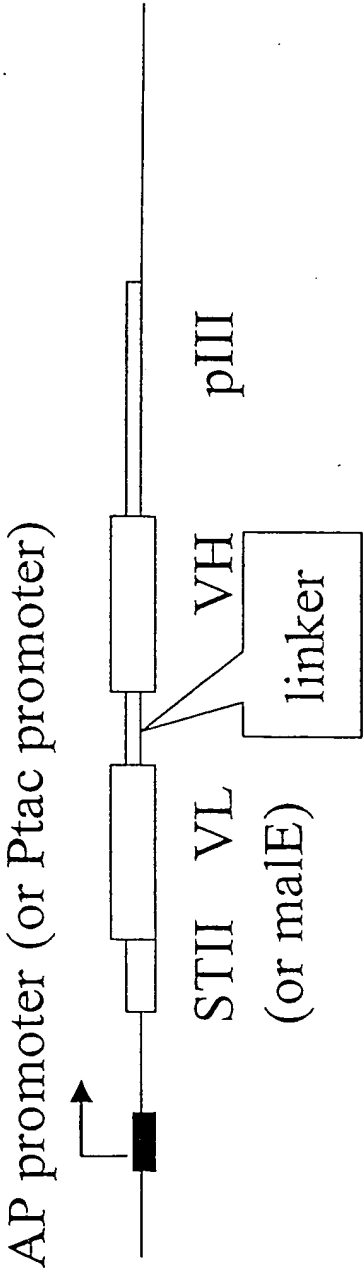


FIG. 34A-B

C. Vector for ScFv-pIII



D. Vector for (ScFv)2-pIII

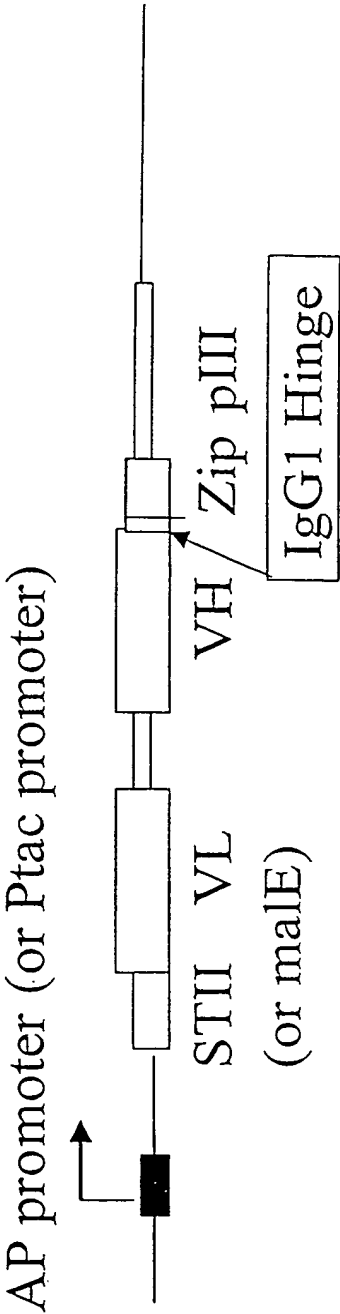
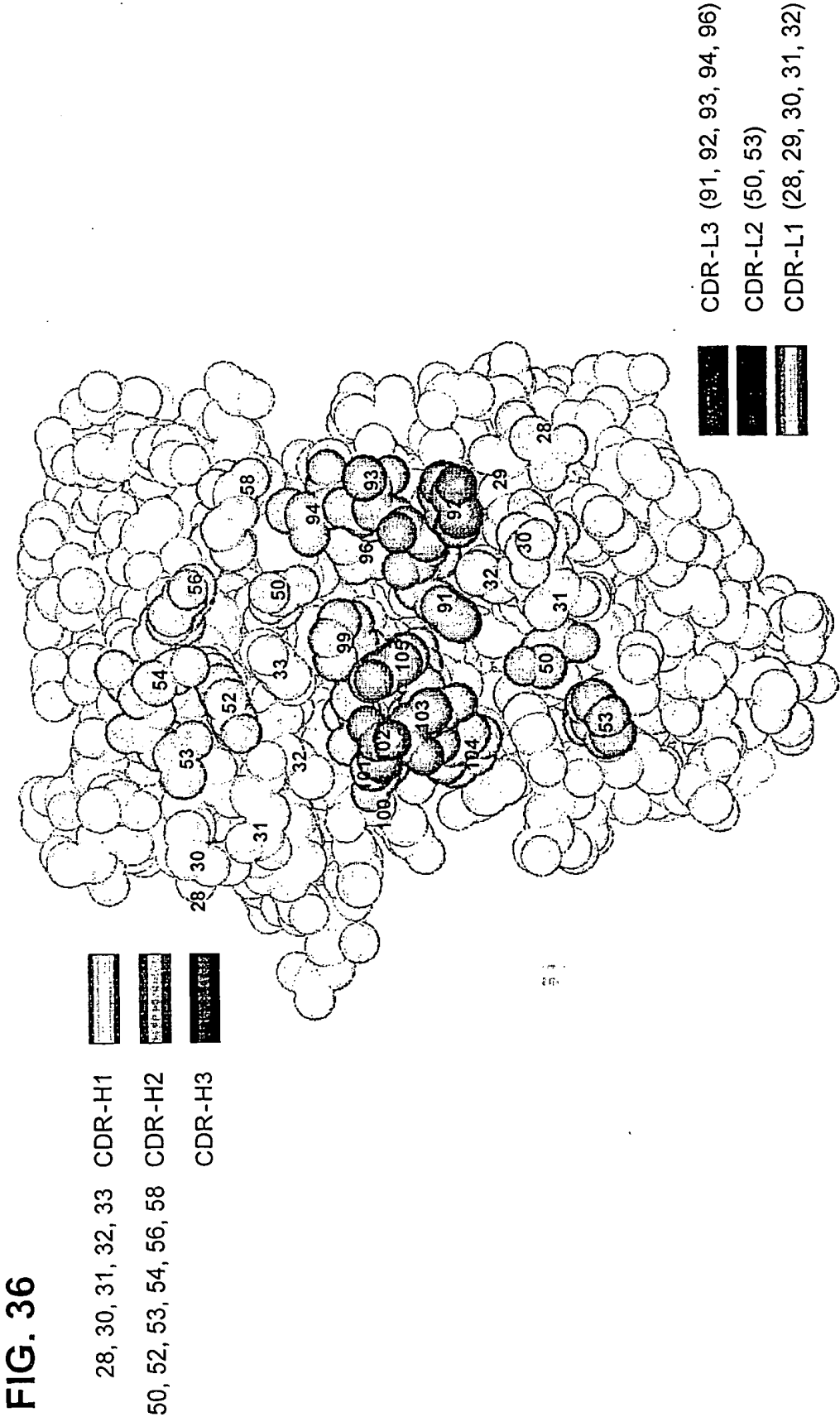


FIG. 34C-D

	28	30	31	32	33	50	52	53	54	56	58	95	96	97	98	99	100	100a	Affinity uM
mVEGF-109	T	G	N	S	W	V	A	T	Y	Y	N	W	G	A	K	G	T	W	0.13
mVEGF-126	N	A	D	S	A	Y	A	Y	D	Y	Y	W	G	W	T	T	N	G	0.58
mVEGF-127	N	D	N	T	A	V	S	H	D	T	Y	W	G	W	E	T	D	G	0.83
mVEGF-130	N	A	D	S	A	L	D	S	S	Y	D	S	R	A	G	Y	T	Y	0.2
mVEGF-136	N	G	K	S	S	W	S	Y	E	A	A	T	S	W	S	K	P	Y	0.45
mVEGF-169	N	T	A	Y	G	V	T	Y	D	D	T	W	G	W	E	A	N	W	0.15
mVEGF-173	T	G	G	S	W	V	Y	T	Y	Y	D	W	G	A	G	G	T	W	0.27
mVEGF-174	T	G	G	S	W	V	S	D	Y	Y	D	W	G	S	G	Y	T	W	0.13
mVEGF-176	S	A	G	Y	D	L	A	Y	A	Y	N	A	A	A	W	A	S	Y	0.7
mVEGF-179	T	T	E	S	G	V	Y	H	D	K	Y	W	W	Y	S	W	N	W	0.13

FIG. 35



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1 GAATCAACT TCTCCATAC TTGATAAGG AATACAGAC ATGAAATC TCATTGTGA GTTGTATTT AAGCTGGCC AAAAAGAAGA AGAGTCGAAT
  CTTAAGTTGA AGAGGTATGA AACCTATTCC TTTATGTCTG TACTTTTAG AGTAACGACT CAACAATAAA TTCGAACGGG TTTTCTTCT TCTCAGCTTA

101 GAACTGTG GCGAGTAGA AGCTTTGGAG ATTATGCTCA CTGCAATGCT TCGCAATATG GCGCAAAATG ACCAACAGCG GTTGATTGAT CAGGTAGAGG
  CTTGACACAC GCGTCCATCT TCGAAACCTC TAATAGCAGT GACGTTACGA AGCGTTATAC CGGTTTTC TGGTGTGCG CAACTAACCTA GTCCATCTCC

201 GGGCGCTGTA CGAGGTAAAG CCGATGCCA GCATTCTGTA CGAGATPACG GAGCTGTGCG GCGATTACGT AAGAAGTTA TTGAAGCATC CTCGTCAAGTA
  CCGCGACAT GCTCCATTTC GGGCTACGGT CGTPAGGACT GCTGCTATGC CTGACACGCG CGCTAATGCA TTTCTTCAAT AACTTCGTAG GAGCAGTCAT

301 AAAAGTTAAT CTTTCAACA GCTGTCAATA AGTTGTACAG GCGGAGCTT ATAGTCGCTT TGTTTTATT TTTTAATGTA TTGTAACTA GTACGCAAGT
  TTTTCAATTA GAAAGTTGT CGACAGTAT TCAACAGTGC CGGCTCTGAA TATCAGCGAA ACAAAATAA AAAATTACAT AAACATTGAT CATGCGTTCA

401 TCACGTAAA AGGGTATGTA GAGGTGAGG TGAATTTATG AAAAGATA TCGCATTTCT TCTGCACT ATGTTGCTTT TTTCTATTGC TACAAATGCC
  AGTGCAATTT TCCCATACAT CTCCAACTCC ACTAATATAC TTTTCTTAT AGGTAAGA AGAAGTGA TACAAGCAAA AAGATAACG ATGTTTACGG
  1 M K K N I A F L L A S M F V F S I A T N A
    *start of stII signal sequence
    *met

501 TATGCAGATA TCCAGATGAC CCAGTCCCG AGCTCCCTGT CCGCTCTGT GGGCGATAGG GTCACCATCA CCTGCGGTGC CAGTCAGGAT GTGTCCACTG
  ATACGTCTAT AGGTCTACTG GGTACGGGC TCGAGGGACA GCGGAGACA CCGCTATCC CAGTGTAGT GGACGGCAG GTCAGTCCCTA CACAGGTGAC
  22 Y A D I Q M T Q S P S S L S A S V G D R V T I T C R A S Q D V S T A
    *start of light chain
    *CDR-L1

601 CTGTAGCCCTG GTATCAACAG AAACAGGAA AAGCTCCGAA GCTTCTGATT TACTCGGAT CCTTCCCTA CTCGTGATC CTTCTCGCT TCTCTGCTAG
  GACATCGGAC CATAGTTGTC TTGCTCCTT TTCGAGCTT CCAAGACTAA ATGAGCGTA GGAAGGAGT GAGACCTCAG GGAAGAGCGA AGAGACCATC
  56 V A W Y Q Q K P G K A P K L L I Y S A S F L Y S G V P S R F S G S
    *CDR-L2

701 CGGTCCGGG ACGGATTTCA CTCTGACCAT CAGCAGTCTG CAGCCGGAAG ACTTCGCAAC TTATTACTGT CAGCAATCTT ATACTACTCC TCCACGTTT
  GCCAAGGCC TCCTTAAGT GAGACTGGTA GTGCTGAGAC GTGCGCTTC TGAAGCTTG AATATGACA GTCTTAGNA TATGATGAGG AGGGTGAAG
  89 G S G T D F T L T I S S L Q P E D F A T Y Y C Q Q S Y T T P P T F
    *CDR-L3

801 GGACAGGGTA CCAAGTGA GATCAACGA ACTGTGGCTG CACCATCTGT CTTCATCTTC CCGCATCTG ATGAGCAGTT GAAATCTGGA ACTGCCCTCTG
  CCTGTCCCAT GGTCCACCT CTAGTTGCT TGACACGAC GTGGTAGCA GAAGTGAAG GCGGTAGAC TACTCGTCAA CTTTAGACCT TGACGGAGAC
  122 G Q G T K V E I K R T V A A P S V F I F P P S D E Q L K S G T A S V

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FIG. 37A

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901 TTGTGTGGCT GCTGATATAC TTCTATCCCA GAGAGGCCAA ACTACAGTGG AAGGTGGATA AGCCCTCCA ATCGGTAAAC TCCAGGAGA GTGTACAGA  
 AACACACGGA CGACTATATG AAGATAGGCT CTCTCCGGTT TCATGTCACC TTCCACCTAT TCGGGAGGT TAGCCCATTT AGGTCCCTCT CACAGTGTCT  
 156 V C L L N N F Y P R E A K V Q W K V D N A L Q S G N S Q E S V T E  
 101 GCAGACACAGC AAGGACAGCA CCTACAGCCT CAGCAGCAC CTGACGCTGA GCAAGCAGA CTACGAGAA CACAAAGTCT AGCCTGCGA AGTCAACCAT  
 CGTCTGTG TCCGTGCT GATGTCGGA GTCGTGCTGG GACTGCGACT CGTTTGTCT GATGCTCTTT GTGTTTCAGA TCGGACGCT TCAGTGGGTA  
 189 Q D S K D S T Y S L S S T L T L S K A D Y E K H K V Y A C E V T H  
 1101 CAGGCGCTGA GCTCGCCCT CACAAAGCC TTCAACAGG GAGAGTGG TGCAGCTCC GGTATGCTG ATCGGAACCG TTTCGCGGT AAGGACCTGG  
 GTCCGGACT CGAGGGGCA GTGTTCTCG AAGTTCTCC CTCTCACACC ACGTGCAGG CCAATCCGAC TAGGCTGGC AAGGCGGCA TTCTTGACAC  
 222 Q G L S S P V T K S F N R G E C G A S S G M A D P N R F R G K D L A  
 'end of light chain, start of gD tag  
 1201 CATAACTCGA GGCTGATCCT CTACGCCGGA CGCATCGTGG CCTACTAGC CAAGTTCACG TAAAAAGGT AACTAGAGGT TGAGGTGATT TTATGAAAA  
 GTATTGAGCT CCGACTAGGA GATCGGCCCT GCGTAGCACC GGGATCAGC GTTCAAGTGC ATTTTCCCA TTGATCTCCA ACTCCACTAA AATACTTTT  
 256 O  
 -23  
 M K K  
 'start of stII  
 1301 GAATATCGA TTCTCTCTTG CATCTATGTT CTTTTTCT ATGCTACAA AGCGTAGC TGAGTTTCAG CTGCTGGAGT CTGCGGTGG CCTGTGTCAG  
 CTTATAGCCT AAGAGAGAC GTAGATACAA GCAAAAGA TAACGATGTT TGGCATGCG ACTCCAGTC GACCACTCA GACCCACC GGACACGTC  
 -20 N I A F L L A S M F V F S I A T N A Y A E V Q L V E S G G G L V Q  
 'start of heavy chain  
 1401 CCAGGGGCT CACTCGGTTT GTCTGTGCA GCTTCTGGCT TCAACATTA AGACACTAT ATACACTGGG TGCTCAGC CCCGGTAAAG GGCCTGGAAT  
 GGTCCCCGA GTGAGGCAAA CAGGACACGT CGAAGACCGA AGTTGTAAT TCTGTGATA TATGTAGCC ACGAGTCCG GGGCCCATTC CCGGACCTTA  
 14 P G G S L R L S C A A S G F N I K D T Y I H W V R Q A P G K G L E W  
 'CDR-H1  
 1501 GGGTGGCAG GATTATCCT ACGAATGGTT ATACTAGATA TGCGATAGC GTCAAGGSC GTTTCATCT AAGGCGAC ACATCCAAA ACACAGCCTA  
 CCCACGTTT CTAAATAGGA TGCTTACCAA TATGATCTAT ACGGCTATCG CAGTTCCGG CAAAGTGATA TTGCGGTCTG TGTAGTCTT TGTGTGGAT  
 48 V A R I Y P T N G Y T R Y A D S V K G R F T I S A D T S K N T A Y  
 'CDR-H2  
 1601 CCTACAAATG AACAGCTTA GAGCTAGGA CACTGCGCTC TATTATGTA GCGCTGGG AGGGAGCGG TTTCTATGTA TGGACTACTG GGTCAAGGA  
 GGATTTTAC TTGTGCAAT CTGACTCCT GTGACGCGAG ATATATACAT CGCGACCCC TCCCTGCGG AAGATACCAT ACCTGATGAC CCCAGTTCCT  
 81 L Q M N S L R A E D T A V Y Y C S R W G G D G F Y A M D Y W G Q G  
 'CDR-H3  
 1701 AACTAGTCA CGGTCTCTC GGCCTCCACC AAGGGCCCAT CGGTCTTCCC CTCTCCAGA GCACCTCTGG GGGCACAGG GGCCTGGCT  
 TGTGATCAGT GGCAGAGGAG CCGGAGGTGG TTCCCGGTA GCCAAGGG GAGCGGTGG AGGAGTCT CGTGGAGACC CCCGTGTCG CGGACCCGA  
 114 T L V T V S S A S T K G P S V F P L A P S S K S T S G G T A A L G C

FIG. 37B

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1801 GCCTGGTCAA GGACTACTTC CCGAACCGG TGACGGTGTG GTGGAATCA GGGCCCTGA CCAGCGCGT GCACACCTTC CCGGTGTCC TACAGTCCTC  
 CGGACGAGT CCGTAGAAG GGGCTGGCC ACTGCCACAG CACTTGAGT CCGCGGACT GGTGTGGAAG GGCACACAGG ATGTGAGGAG  
 148 L V K D Y F P E P V T V S W N S G A L T S G V H T F P A V L Q S S  
 1901 AGGACTCTAC TCCCTCAGCA GGGTGTGAC CGTGCCCTCC AGCAGCTTGG GCACCCAGAC CTACATGTC AACGTGATC ACACGCCAG CAACACCAAG  
 TCCTGAGATC AGGGAGTCGT CGCACCACTG GCACGGGAGG TGTCTGAACC CGTGGGTCTG GATGTAGACG TTGCACTTAG TGTTCGGGTC GTTGTGGTTC  
 181 G L Y S L S S V V T V P S S S L G T Q T Y I C N V N H K P S N T K  
 2001 GTGCAACAAG AAGTTGAGCC CAATCTTGT GACAAACTC ACCTCAGTGG CGGTGGCTCT GGTTCGGTG ATTTGATTA TGAAGAATG GCAACGCTA  
 CAGCTGTTCT TTCACTCGG GTTTAGACA CTGTTTGGAG TGGAGTCACC GCACCCAGA CCAAGGCCAC TAAACTTAAT ACTTTCTTAC CGTTTGGAT  
 214 V D K K V E P K S C D K T H L S G G S G S G D F D Y E K M A N A N  
 \*end of heavy chain  
 \*start of gene III coat protein (267-end)  
 2101 ATAAGGGGGC TAGACCGAA AATGCCGATG AAAACGGCT ACAGTCTGAC GCTAAAGCA AACTTGATC TGTGCTACT GATTAGGGTG CTGCTATCGA  
 TATTCCTCCG ATACTGGCTT TTACGGCTAC TTTTGGCGA TGTGAGACTG CGATTTCCGT TTGAACTAG ACAGCGATGA CTAATGCCAC GACGATAGCT  
 248 K G A M T E N A D E N A L Q S D A K G K L D S V A T D Y G A A I D  
 2201 TGGTTTCATT GGTGACGTTT CCGGCTTGC TAATGGTAAT GGTGCTACTG GTGATTTGC TGGCTCTAAT TCCCAATGG CTCAACTCGG TGACGGTGT  
 ACCAAGTAA CCACCTGCAA GGCCTGAACG ATTACCATTA CCAGATGAC CACTAAACG ACCAGATTA AGGTTTACC GAGTTCAGCC ACTGCCACTA  
 281 G F I G D V S G L A N G N G A T G D F A G S N S Q M A Q V G D G D  
 2301 AATTCACCTT TAATGAATAA TTTCCGTCAA TATTTACCTT CCGTCCCTCA ATCGCTGAA TGTGCGCCTT TGTCTTTAG CCGTGTAAA CCATATGAAT  
 TTAGTGGAA ATTACTTATT AAAGGCAGTT ATAAATGNA GGGAGGAGT TAGCCACTT ACAGGGGNA AACAGAAATC GCGACCATTT GGTATACTTA  
 314 N S P L M N N F R Q Y L P S L P Q S V E C R P F V F S A G K P Y E F  
 2401 TTTCTATTGA TTGTACAAA ATAACTTAT TCCGTGGTGT CTTTGGCGTT CTTTATATG TTGCCACCTT TATGTATGA TTTTCTACGT TTGCTAACAT  
 AAAGATACT AACACTGTTT TATTTGAATA AGCACCACA GNAACGAAA GAAATATAC AACGTGGA ATACATACAT AAAGATGCA AACGATTGTA  
 348 S I D C D K I N L F R G V F A F L L Y V A T F M Y V F S T F A N I  
 2501 ACTGCTTAAT AAGAGTCTT AATCATGCCA GTTCTTTTGG CTAGCGCGC CCTATACCTT GTCTGCCTCC CCGCTTGG TCGCGGTGCA TGGAGCCCGG  
 TGACGCATTA TTCTCAGAA TTAGTAGGT CAAGAAACC GATCGCGCG GATATGGA GATCGGAGG GCGCAACGC AGCGCCACGT ACCTCGGCCC  
 381 L R N K E S O  
 2601 CCACCTCGAC CTGAATGGA GCGCGGCGCA CCTGCTAAC GGATCACC CTCCAAGAT TGGAGCCAT CAATTCTTC GGAGAACTGT GAATGCGCAA  
 GGTGAGCTG GACTTACCTT CCGCGCGCGT GGAGCGATG CCTAAGTGGT GAGTCTTA ACCTCGTTA GTTAAGAAG CCTCTTGACA CTTACGCGTT  
 2701 ACCAACCCCTT GGCAGACAT ATCCATCGCG TCCGCCATCT CCAGCAGCGG CACGCGGCG ATCTCGGCA GCGTTGGTC CTGGCCACGG GTGCGCATGA  
 TGGTTGGGA CCGTCTTGT TAGGTAGCGC AGCGGTAGA GGTGTCGCG GTGCGCGCG TAGAGCCCT CCAACCCAG GACCGGTGCC CACCGTACT  
 2801 TCGTGTCTCT GTCTGTAGG ACCGGCTAG GCTGCGGGG TTGCTTACT GGTAGCAGA ATGAATCAC GATACGCGAG CGAACGTGA GCGACTGTG  
 AGCACGAGA CAGCACTCC TGGGCCGATC CGACGCGCCC AACGAAATGA CCAATCGTCT TACTTAGTGG CTATGCGCTC GCTTGCACTT CGCTGACGAC  
 2901 CTGCAAAACG TCTCGGACCT GAGCAACAAC ATGAATGTC TTGCTTTCC GTGTTTCTGA AAGTCTGAA ACGCGGAAGT CAGCGCCCTG CACCATATG  
 GACGTTTGC AGCGCTGGA CTCGTTGTTG TACTTACCAG AAGCCAAAG CACAAGCAT TTCAGACCTT TCGGCTTCA GTGCGGGGAC GTGTTATATC

FIG. 37C

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3001 TTCCGGATCT GCATCGCAGG ATGCTGCTGG CTACCTCTGG GAACACCTAC ATCTGTATTA ACGAAGCGCT GGCATTGACC CTGAGTGATT TTTCTCTGGT  
 AAGGCCATAGA CGTAGCGTCC TACGACGACC GATGGGACAC CTTGTGGATG TAGACATATAT TGCTTCGCGA CGGTAACTGG GACTCACTAA AAAGAGACCA  
 3101 CCGCGCCGAT CCAATACGCC AGTTGTTTAC CCTCACAACG TTCCAGTAACT CCGGCGATGT CATCATCAGT AACCCGTATC GTGAGCATCC TCTCTCGTTT  
 GGGCGGCGTA GGTATGCGG TCAACAAATG GAGTGTGTC AAGTCACTG GCCCGTACAA GTAGTAGTCA TTGGGCGATG CACTCGTAGG AGAGAGCAAA  
 3201 CATCGGTATC ATTAACCCCA TGAACAGAAA TTCCGCCCTTA CAGGAGGGA TCAAGTGACC AACAGGAAA AACCCGCCCT TAACATGGCC CGCTTTATCA  
 GTAGCCATAG TAATGGGGGT ACTGTCTTT AAGGGGAAT GTGCTCCGT AGTTCACATG TTGTCTCTT TTGGCGGGA ATTGTACCGG CGCAATATAGT  
 3301 GAAGCCAGAC ATTAACGCTT CTGGAGAAAC TCAACGAGCT GGACGCGAT GAACAGGCGA ACATCTGTGA ATCGCTTCAC GACCACGCTG ATGAGCTTTA  
 CTTCCGCTCTG TAATGCGAA GACCTCTTTG AGTGTCTGA CCTGGGCTTA CTTGTCCGTC TGTAGACACT TAGCGAAGTG CTGGTGGAC TACTCGAAAT  
 3401 CCGCAGGATC CGGAATGTGT AAACGTTAAT ATTTGTGTTA AATTCGCGTT AAATTTTCT TAATCAGCT CATTTTAA CCAATAGGCC GAATTCGGCA  
 GGGCTCTAG GCCTTTAA TTTGCAATTA TAAACAAT TTAAGCGCAA TTAAGTCTGA ATTTAGTCTG GTATATCCGG CTTTAGCCCT  
 3501 AAATCCCTTA TAAATCAAAA GATAGACCG AGATAGGCTT GAGTGTGTT CAGTTTGA ACAAGAGTCC ACTATTAAAG AACGTGAGT CCAAGTCTAA  
 TTATAGGAAT ATTTAGTTT CTTATCTGCG TCTATCCCAA CTCACACAA GGTCAAACT TGTTCTCAGG TGATAATTTT TTGCACCTGA GGTTCAGTT  
 3601 AGGCGGAAA ACCGCTATC AGGCTATGG CCCACTACGT GAACATCAC CCTAATCAG TTTTGTGGG TCGAGGTGCC GTAAAGCACT AAATCGGAAC  
 TCCCGCTTT TGGCAGATAG TCCGATACC GGTGATGCA CTTGTAGTG GGTATGTTT AAAAACCCTC AGCTCCACGG CATTTCTGTA TTTAGCCTTG  
 3701 CCTAAAGGGA GCCCGCAT TAGAGCTTGA CCGGGAAGC CCGGGAACGT GCGGAGAAAG GAAGGAAGA AAGCGAAAG AGCGGGCGCT AGGCGCTGG  
 GGATTTCCCT CCGGGGCTAA ATCTCGAAT GCCCTTTTCG CCGCTTTGA CCGCTTTTC TTCCCTTCTC TCGGCTTCC TCGCGCGGA TCCCAGACC  
 3801 CAAGGTAGC GGTACAGCT CCGCTAACCA CCACACCCG CCGGTTAAT GCGCGCTAC AGGCGCGCTC CGGATCCTGC CTCGCGCGTT TCGGTGATGA  
 GTTCACATCG CCAGTGGAC GCGCATTTGT GGTGTGGCG CCGCAATTA CCGCGCATG GCTTAGGACG GAGCGCGCAA AGCCACTACT  
 3901 CGGTGAAAC CTCTGACACA TGCAGCTCC GAGACGCTC ACAGTTTTC TGTAGCGGA TCCCGGGAGC AGACAAGCCC GTACAGGCGC GTCAGCGGT  
 GCCACTTTTG GAGACTGTGT ACCTCGAGG CCTCTGCCAG TGTGAAACAG ACATTCGCTT CCGGCTCTC AGGCGCTCG TCTGTTCGGG CAGTCCGCCA  
 4001 GTTGGCGGGT GTCGGGCGC AGCCATGACC CAGTCACTGA CCGATAGCG GGTATCTAT AGTGTATCT GGCCTAACA TCGGGCATCA GAGCAGATTG TACTGAGAGT  
 CAACCGCCCA CAGCCCCCG TCGGTACTGG CAGTATGCC TCAATATGA CCGAATGAT AGCCCTATG ACCTCTAAC ATGACTCTCA  
 4101 GCACCATATG CCGTGTGAAA TACCGCACAG ATGCTAAGG AGAAATACC GCATCAGGG CTCTTCCGT TCTCTGCTCA CTGACTCGCT GCGTCTGGTC  
 CGTGTATAC GCCACATTT ATGGCTGTCT TACGCATTC TCTTTATGG COTATCCG GAGAGCGGA AGGAGCGAGT GACTGAGCGA CCGGAGCCAG  
 4201 GTTCGGTGC GGCAGCGGT ATCAGCTCAC TAGTCGATG AGTTTCCGCT ATTAGCCAA TAGGTCTCTT AGTCTCTAT TCGCTCTCTT CGTTTTCGG  
 CAACCCGAC CCGCTCGCA TAGTCGATG TAGTCGATG AGTTTCCGCT ATTAGCCAA TAGGTCTCTT AGTCTCTAT TCGCTCTCTT CGTTTTCGG  
 4301 AGCAAAAGC CAGGACCGT AAAAGGCGG CGTCTCTGC GTTTTCCAT AGGCTCCGC CCCCTGACGA GCATCAAAA AATCGACGCT CAAGTCAGAG  
 TCGTTTTCG GTCTTGGCA TTTTTCGCG GCAACGACG CAAGAAGTA TCCGAGCGG GGGGACTGCT CGTAGTGTCT TTAGCTGGA GTTCAGTCTC  
 4401 GTGGCGAAG CCGACAGGAC TATAAGATA CCAGCGTTT CCCCTGGA GCTCCTCTCT GGTCCGACCC GTTCCGACCC TGCGCTTAC CGGATACCTG  
 CACCGCTTG GGTGTCTCTG ATATTTCTAT GGTCCGCAA GGGGACCTT CAGAGAGGA CAAGGCTGG ACAGCGAATG GCCTATGGAC

FIG. 37D



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4501 TCCGCTTTTCC TCCCTTCGGG AAGCGTGGG CTTTCTCAT GGTACGCTG TAGGTATCTC AGTTCGGTGT AGTTCGGTTCG CTCACAGCTG GGCTGTGTGC  
 AGCGGGAAG AGGGAAGCCC TTCCGACCCG GAAAGAGTAT CGAGTGGGAC ATCCATAGAG TCAAGCCACA TCCAGCRAAG GAGGTTCCGAC CCGACACACG  
 4601 ACAGACCCCC CGTTACGCCC GACCGCTGG CCTTATCCGG TAATATCGT CTGAGTCCA ACCCGTAAG ACAGACTTA TCGCCACTGG CAGCAGCCAC  
 TCGTTGGGG GCAAGTCGGG CTGGGACGC GGAATAGGCC ATGATAGCA GAACTCAGGT TGGGCCATTTC TGTCGTGAAT AGCGGTGACC GTCGTGGTG  
 4701 TGGTAACAGG ATTACAGAG CGAGGTATGT AGGCGTGTCT ACAGATTCT TGAAGTGGTG GCCTAATCTAC GGCTACACTA GAAGCACACT ATTTGGTATC  
 ACCATTGCC TAATCGTCTC GCTCCATACA TCCGCCACGA TGTCTCAAGA ACTTCCAC CCGATTGATG CCGATGTGAT CTTCTGTCA TAAACCATAG  
 4801 TCGGCTCTGC TGAAGCCACT TACCTTCGGA AAAAGAGTTG GTAGCTCTTG ATCCGGCAAA CAAACCAACCG CTGCTAGCGG TGGTTTTTTT GTTTGCAAGC  
 ACGGAGACG ACTTCGGTCA ATGGAAGCCT TTTTCTCAAC CATCGAGAAC TAGGCCGTTT GTTTGGTGGC GACCATCGCC ACCAAAAAA CAAACGTTCC  
 4901 AGCAGATTAC GCGCAGAAAA AAAGGATCTC AAGAAGATCC TTGATCTTT TGTATCTTT ATCCGGCAAA CAAACCAACCG CTGCTAGCGG TGGTTTTTTT GTTTGCAAGC  
 TCGTCTAATG CCGCTCTTTT TTCTCTAGAG TTCTTCTAGG AAACTAGAAA AGATGCCCA GACTGCGAGT CACCTTGCTT TTGACTGCAA TTCCCTAAAA  
 5001 GGTCTATGAG TTATCAAAAA GGATCTTCTAC CTAGATCCCT TTAAATTA AAATTAATTA AAATTAATTA AAATTAATTA AAATTAATTA AAATTAATTA AAATTAATTA  
 CCAGTACTCT AATAGTTTTT CCTAGAAAGT GATCTAGGAA AAATTAATTA AAATTAATTA AAATTAATTA AAATTAATTA AAATTAATTA AAATTAATTA  
 5101 AGTTACCAAT GCTTAATCAG TGAGGCACCT ATCTCAGCGA TGTGTCTATT TGTGTCTATT TGTGTCTATT TGTGTCTATT TGTGTCTATT TGTGTCTATT  
 TCAATGGTTA CGAATTAGTC ACTCCGTGGA TAGAGTCGCT AGACAGATTA AGCAAGTAGG TATCNAACGA CTGAGGGGCA GCACATCTAT TCATGCTATG  
 5201 GGGAGGGGTT ACCATCTGCC CCCAGTCTG CAATGATACC GCGAGACCCA CCGTCAACCG CTCCAGATT ATCAGCAATA AACCAAGCCAG CCGGAAGGGC  
 CCGTCCCGAA TGGTAGACG GGGTACGAC GTTACTATGG CCGTCTGGT GCGAGTGGC GAGGTCTAAA TAGTCGTAT TTGGTGGTTC GGCTTCCCG  
 5301 CGAGGCGAGA AGTGTCTCTG CAATTTATC CCGCTCCATC CAGTCTATTA ATGTTGGCG GGAAGCTAGA GTAAGTAGTT CGCCAGTTAA TAGTTTGGCG  
 GCTCGCGTCT TCACCAGGAC GTTGAATAG GCGGAGGTAG GTCAGATAT GTCAACGGC CCGTCCGATCT CATTCAATCA CCGGTCAAT ATCAAAACGG  
 5401 AACGTTGTTG CCATTGCTGC AGGCATCTG GTGTACGCT CCGTCTGGT TATGGCTTCA TTCAGCTCCG GTTCCCAACG ATCAAGGGCA GTTACATGAT  
 TTGCAACAC GGTACGACG TCCGTAGCAC CACAGTGGCA GCAGCAACCC ATACCGAAGT AGCTCGAGC CNAAGGTGC TAGTTCGGCT CAATGTACTA  
 5501 CCCCCATGTT GTGCAAAAA GCGGTAGCT CCGTCTGGT TCCGATCGTT GTCAAGAGTA AGTTCGGCG AGTGTATCA CTCATGGTTA TGGCAGCACT  
 GGGGTACAA CAGGTTTTT CCGCAATCGA GGAAGCCAGG AGGCTAGCAA CAGTCTCAT TCACCGCGG TCACAATAGT GAGTACCAAT ACCGTCTGA  
 5601 GCATTAATCT CTTACTGTCA TGCCATCCCT AAGATCCCTT TGTGTACTG GTGAGTACTC AACCAAGTCA TTCTGAGTAT TCTGAGTATG GCGACCGAGT  
 CGTATTAAGA GAATGACACT ACGGTAGGCA TTCTAGGAAA AGACACTGAC CACTCATGAG TTGTTCCAGT AAGACTCTTA TCACATACGC CGCTGGCTCA  
 5701 TGCCTTTGCC CCGCTCAAC ACGGATTAAT ACCGCGCCAC ATAGCAGAAC TTAAAGTG CTCATCATTT TCGGGGCGA AAACCTCAA  
 ACAGAAACG GCGCAGTTG TCCCTATTA TGGCGCGTG TATCGTCTT AAATTTTAC GAGTAGTAAC CTTTGGCAAG AAGCCCCGT TTTGAGATT  
 5801 GGATCTTACC GCTGTGAGA TCCAGTTTCA TGTAAACCCAC TGTGACCC TGTGACCC TGTGACCC TGTGACCC TGTGACCC TGTGACCC  
 CCTAGATGG CGACACTCT AGGTCAAGCT ACATTGGTG AGCAGCTGGG TTGACTAGAA GTGCTAGAAA ATGAAAGTGG TCGCAAAAGAC CCACCTCGTTT  
 5901 AACAGGAGG CAAATGCCG CAAAAGGG AATAAGGGG ACACGGAAT GTTGAATACT CATACTCTTC CTTTCTCAAT ATTATTGAAG CATTATCAG  
 TTGCTCTTCC GTTTACGGC GTTTTTTCC TTATTCCCG TGTGCTTTA CAACCTATGA GTATGAGAG GAAAAAGTTA TAATTAACITC GTAAATAGTC

FIG. 37E

6001 GGTATGTGTC TCATGAGCGG ATACATATTT GAATGTATTT AGAAAATAA ACAATAGGG GTTCCGGCCA CATTTCCCGC AAAAGTGCCA COTGACGTCT  
 CCAATAACAG AGTACTCGCC TAIGTATAA CTTACATAA TCTTTTATT TGTATTATCC CAAGGCCGGT GTRAAAGGGC TTTTCACGGT GGAATGCAGA  
 6101 AAGAACCAT TATTATCATG ACATTAACCT ATAAAAATAG GGGTACAG AGGCCCTTTC GTCTTCAATA CAGGTAGACC TTTCTAGAG ATGTACAGTG  
 TTCTTTGGTA ATAAATAGTAC TGTAAATGGA TATTTTATC CGCATAGTGC TCCGGGAAG CAGAATTAT GTCCATCTGG AAAGCATCTC TACATGTCAC  
 6201 AAATCCCCGA AATTATACAC ATGACTGAAG GAAGGAGCT CGTCAATCCC TGCCGGGTTA CGTCACCTAA CATCAGTCTT ACTTTAAAAA AGTTTCCACT  
 TTTAGGGGCT TTAATATGTG TACTGACTTC CTTCCTCGA GAGTAAAGG ACGGCCCAAT GCAGTGGATT GTAGTGACAA TGAATTTTT TCAAAAGTGA  
 6301 TGACACTTTG ATCCCTGATG GAAAAGCCAT AATCTGGGAC AGTAGAAAG GCTTCATCAT ATCAAAATGCA ACGTACAAAAG AAATAGGGCT TCTGACCTGT  
 ACTGTGAAC TAGGGACTAC CTTTTCGGTA TTAGACCTG TCACTTTCC CGAAGTAGTA TAGTTTACGT TGCATGTTTC TTTATCCCGA AGACTGGACA  
 6401 GAAGCAACAG TCAATGGGCA TTTGTATAG ACAACTATC TCACACATCG ACAACCAAT ACAATACAGG TAGACCTTTC GTAGAGATGT ACAGTGAAT  
 CTTCTGTGTC AGTTACCCGT AACATATTC TGTGTATAG AGTGTGTAG TGTGTGTGTTA TGTATGTGTC ATCTGGAAAAG CATCTCTACA TGTCACTTTA  
 6501 CCCCAGAAAT ATACACATGA CTGAAGGAAG GAGCTCGTC ATTCCCTGCC GGTTACGTC ACCTAACATC ACTGTTACTT TAAAAAGTT TCCACTTGAC  
 GGGGCTTTAA TATGTGTACT GACTTCCTTC CCTCGAGCAG TAAGGGACGG CCCAATGCAG TGGATTGTAG TGACAATGAA ATTTTTCMA AGGTGAACGTG  
 6601 ACTTTGATCC CTGATGGAAA ACGCATATC TGGGACAGTA GAAAGGCTT CATCATATCA AATGCAAGT ACAAGAAAT AGGGCTTCTG ACCTGTGAAG  
 TGAACTAGG GACTACCTTT TGGGTATTAG ACCCTGTCAT CTTTCCGAA GTAGTATAGT TTACGTTGCA TGTTCCTTTA TCCCGAAGAC TGGACACTTC  
 6701 CAACAGTCAA TGGGCAATTTG TATAAGACAA ACTATCTCAC ACATCGACAA ACCAATCAA TCTACAGTA GACCTTTCGT AGAGATGTAC AGTGAATCC  
 GTTGTGAGTT ACCCGTAAAC ATATTCTGTT TGTATAGTGT TGTAGCTGTT TGGTTATGTT AGATGTCCAT CTGAAAAGCA TCTCTACATG TCACTTTAGG  
 6801 CCGAATTTAT ACATGACT GAAGGAAGG AGCTCGTCAT TCCTCGCGG GTTACGTCAC CTAACATCAC TGTACTTTA AAAAGTTTC CACTTGACAC  
 GGCCTTTAATA TGTGTACTGA CTTCTTCCC TCGAGCAGTA AGGGACGGCC CAATGCAGT GATTGTAGT ACAATGAAT TTTTCAAG GTGAACGTG  
 6901 TTTGATCCCT GATGAAAAC GCATAATCTG GGACAGTAGA AAGGGTTCA TCATATCAA TGCACGTAC AAAGAAATAG GGCTTCTGAC CTGTGAAGCA  
 AAACTAGGA CTACCTTTG CGTATTAGAC CCGTCACTCT TTCCCGAGT AGTATAGTTT ACGTTGCATG TTTCTTTATC CCGAAGACTG GACACTTCGT  
 7001 ACAGTCAATG GGCATTGTA TAAGACAAAC TATCTCACAC ATCGACAAC CAATACAATC  
 TGTCACTTAC CCGTAAACAT ATTCTGTTG ATAGAGTGTG TAGCTGTTG GTTATGTTAG

FIG. 37F

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1 GAATCAACT TCTCATACT TTGGATAAGG AATACAGAC ATGAAATC TCATTGCTGA GTTGTTATTT AGCTTGCCC AAAAGAAGA AGAGTCGAAT  
 CTTAAGTTGA AGAGGTATGA AACCTATTCC TTATGTCGT TACTTTTAG AGTAAGGACT CAACAATADA TTTTCTTCT TCTCAGCTTA  
 101 GAACGTGTG CGCAGGTAGA AGCTTTGGAG ATTATCGTCA CTGCAATGCT TCGCAATATG GCGCAAAATG ACCAACAGCG GTTGATTGAT CAGGTAGAGG  
 CTTGACACAC CGGTCCATCT TCGAAACCTC TAATAGCACT GACGTACGA AGCGTTATC CGGTTTTAC TGGTTGTGCG CAACTAACATA GTCCATCTCC  
 201 GGGCGCTCTA CGAGGTAAAG CCCGATGCCA GCATTCCCTGA CGACGATACG GAGCTCTGCG GCGATTACGT AAAGAAGTTA TTGAAGCATC CTCGTCAGTA  
 CCCCGGACAT GCTCCATTTC GGGTACGGT CGTAGGACT GCTGCTATGC CTCGACGACG CGCTAATGCA TTTCTTCAAT AACTTCGTAG GAGCAGTCAT  
 301 AAAAGTTAAT CTTTCAACA GCTGTCAATGA AGTTGTCACG GCGGAGACTT ATAGTCGCTT TGTTTTATT TTTTAAATGA TTTGTAACATA GTACGCAAGT  
 TTTTCAATTA GAAAGTTGT CGACAGTATT TCAACAGTGC CGGCTCTGAA TATCAGCGAA ACBAAAATAA AAAATTACAT AAACATTGAT CATGCGTTCA  
 401 TCACGTAAAA AGGGTATGPA GAGTTTGAGG TCAATTTATG AAAAGAATA TCGCATTTCT TCTTGCATCT ATGTTCTGTT TTTCTATTGC TACAAATGCC  
 AGTGCATTTT TCCCATACAT CTCCAACCTC ACTAAATAC TTTTCTTAT AGCGTAAAGA AGAACGTAGA TACAAGCAAA AAAGATAACG ATGTTTACGG  
 M K K N I A F L L A S M F V F S I A T N A  
 \*start of stII sequence  
 501 TATGCATCCG ATATCCAGAT GACCCAGTCC CCGAGCTCCC TGTCGGCTC TGTCGGCGAT AGGTCACCA TCACCTGCGG TGCCAGTCAG GATGTGTCCTA  
 ATACGTAGGC TATAGTCTA CTGGGTACGG GGCTCGAGG ACAGCGGAG ACACCGCTA TCCAGTGGT AGTGGACGCG ACGGTACGTC CTACACAGGT  
 22 Y A S D I Q M T Q S P S S L S A S V G D R V T I T C R A S Q D V S T  
 \*light chain start  
 601 CTGCTGTAGC CTGGTATCAA CAGAAACACG GAAAGCTCC GAAGCTTCTG ATTACTCGG CATCCTTCTCT CTACCTTCTG GTCCTTCTC GTTCTCTGG  
 GACGACATCG GACCATAGTT GCTTTGGTC CTTTTCGAGG CTTTGAAGAC TAAATGAGCC GTAGGAGGA GATGAGACCT CAGGGAAGAG CGAAGAGACC  
 56 A V A W Y Q Q K P G K A P K L L I Y S A S F L Y S G V P S R F S G  
 \*CDR-L2  
 701 TAGCGGTCC GGGACGGATT TCACCTGAC CATCAGCAGT CTGCAGCGG AAGACTTGGC AACTATTAC TGTACAGCAT CTATACTAC TCCTCCACG  
 ATCGCCACGG CCTCGCTAA AGTGAGACTG GTAGTCTCA GAGTCGCGC TTCTGAAGCG TTGAATAATG ACAGTCGTTA GAATATGATG AGGAGGTGC  
 89 S G S G T D F T L T I S S L Q P E D F A T Y Y C Q S Y T T P T  
 \*CDR-L3  
 801 TTGGGACAGG GTACCAAGGT GGAGATCAAA CGAAGTGG CTGCACCATC TGTCTTATC TTCCGGCCAT CTGATGAGCA GTTGAATCT GGAAGTGCCT  
 AAGCCGTCC CATGGTTCCA CCTCTAGTTT CTTGACACC GACGTGTAG ACAGAAGTAG AAGGCGGTA GACTACTCGT CAACTTAGA CTTGACCGA  
 122 F G Q G T K V E I K R T V A A P S V F I F P P S D E Q L K S G T A S  
 901 CTTGTTGTG CCGCTGAAT AACTTCTATC CCAGAGGCG CAAAGTACAG TGAAGGTGG ATAAGCCCT CCAATCGGGT AACTCCACAG AGAGTGTAC  
 GACACACAC GGACGACTTA TTGAAGATAG GGTCTCTCG GTTTCATGTC ACCTTCCACC TATTGCGGGA GTTAGCCCA TTGAGGTGTC TCTCAGATG  
 156 V V C L L N N F Y P R E A K V Q W K V D N A L Q S G N S Q E S V T

FIG. 38A

1001 AGAGCAGGAC AGCAAGGACA GCACCTACAG CCTACGAGC ACCCTGAGC TGAGCAAGC AGACTAGGAG AAACACAAG TCTAGCCTG CGAGTCACCC  
 TCTCGTCCG TCGTTCCTGT CGTGGATGTC GGAGTCGTG TGGAGTCGG ACTCGTTCC TCTGATGCTC TTTGTGTTTC AGATCGGGAC GCTTCAGTGG  
 189 E Q D S K D S T Y S L S S T L T L S K A D Y E K K V Y A C E V T  
 1101 CATCAGGGCC TGAGTCGCC CGTCACAAG AGCTTCAACA GGGAGAGTG TGTGCCAGC TCCGTRAGG CTGATCCGAA CCGTTTCCGC GGTAAAGGACC  
 GTAGTCCCGG ACTCGAGCGG GCAGTGTTC TCGAAGTTGT CCCTCTCAC ACCACGTCG AGGCCATACC GACTAGGTTT GGCAAGGGC CCATTCCTGG  
 222 H Q G L S S P V T K S F N R G E C G A S S G M A D P N R F R G K D L  
 \*end of light chain, start of gp tag  
 1201 TGGCATACT CGAGGCTGAT CCTCTACGC GGAGCATCG TGGCCCTAGT ACCCACTC ACCTAATAAG GGTAACTAGA GGTGAGGTG ATTTATGAA  
 ACCGTATTGA GCTCCGACTA GGAGATCGG CCTGCGTAGC ACGGGATCA TGGGTTCAAG TGCATTTTC CCATGATCT CCACTCCAC TAAATACTT  
 256 A O M K  
 -23 \*start of stII  
 1301 AAAGAAATTC GCATTTCTTC TTGCATCTAT GTTCGTTTT TCTATTCTTA CAACGGCTA CGCTGAGTT CAGCTGGTGG AGTCTGGCGG TGGCTGGTG  
 TTCTTATAG CGTAAAGAG AACGTAGTA CRAAGCAAAA AGATAAGAT GTTTGCCAT CGGACTCAA GTCGACCACT TCAGACCGCC ACCGGACAC  
 -21 K N I A F L L A S M F V F S I A T N A Y A E V Q L V E S G G L V  
 \*start of heavy chain  
 1401 CAGCCAGGGG GTCRATCCG TTTGTCTGT GCAGTCTG GCTTCAACAT TAAAGACACC TATPACACT GGTCCGTGA GGGCCCGGT AAGGGCCTGG  
 GTCCGTCCCC CGAGTAGGC AAACAGACA CGTCGAGC CGAAGTGTG ATTCTGTGG ATATATGGA CCCAGCAGT CCGGGGCCCA TTCCCGGACC  
 13 Q P G G S L R L S C A A S G F N I K D T Y I H W V R Q A P G K G L E  
 \*CDR-H1  
 1501 AATGGGTGC AAGATTAT CCTACGAATG GTTATACATG ATATGCCAT AGCTCAAG GCCGTTTCA TATAAGCGA GACACATCCA AAACACACG  
 TTACCCAACG TTCTTAATA GATGCTTAC CAATATGATC TATACGGCTA TCGAGATCC CGGCAAGTG ATATTGCCGT CTGTGATGT TTTGTGTGCG  
 47 W V A R I Y P T N G Y T R Y A D S V K G R F T I S A D T S K N T A  
 \*CDR-H2  
 1601 CTACCTACAA ATGAACAGCT TAAGAGTGA GGACACTCC GTCTATTAT GTAGCCGCTG GGGAGGGAC GGCTTCTATG CTATGGACTA CTGGGGTCAA  
 GATGGATGTT TACTTGTGA ATTCTGACT CCTGTGAGG CAGATAATA CATCGCGAC CCTCCCTCG CCGAAGATAC GATACCTGAT GACCCAGTT  
 80 Y L Q M N S L R A E D T A V Y Y C S R W G G D G F Y A M D Y W G Q  
 \*CDR-H3  
 1701 GGAACACTAG TCACCGTTC CTCGCGCTCC ACCAAGGCC CATCGGTCTT CCCCTGGCA CCCTCTCCA AGAGCACTC TGAGGGGCACA GCGGCCCTGG  
 CCTGTGATC AGTGGCAGAG GAGCCGGAG TGGTTCGGG GTAGCCAGAA GGGGACCTT GGGAGAGGT TCTGTGGAG ACCCCCTGT GCGCCGGACC  
 113 G T L V T V S S A S T K G P S V F P L A P S S K S T S G T A A L G  
 1801 GCTCCCTGT CAAGACTAC TTCCCGAAC CGGTGACGT GTCTGGGAC TCAGGGGCC TCAGGACCGG CGTGCACACC TTCCCGGCTG TCCTACAGTC  
 CGACGGACCA GTTCTGATG AAGGGCTTG GCCATGCCA CAGCACTTG AGTCCGGG ACTGTGCGC GCACGTGTGG AAGGGCGAC AGGATGTGAG  
 147 C L V K D Y F P E P V T V S W N S G A L T S G V H T F P A V L Q S

FIG. 38B

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1901 CTCAGGACTC TACTCCCTCA GCAGGTGGT GACGTGCCC TCCAGCAGT TGGCACCAC GACCTACATC TCCAACGTGA ATCACAAGCC CAGCAACACC  
 GAGTCCCTGAG ATGAGGGAGT CGTCGCACCA CTGGCAGCGG AGGTGCTGA ACCCTGGGT CTGGATGTAG ACGTTCACT TAGTGTTCGG GTCGTTGTGG  
 180 S G L Y S L S S V V T V P S S S L G T Q T Y I C N V N H K P S N T  
 2001 AAGTCTGACA AGAAGTTGA GCCCAATCT TGTGACAAA CTCAGCGCG CATGAACAG CTAGAGACA AGGTGGAAGA GCTACTCTCC AAGAACTACC  
 TTCCAGCTGT TCTTTCRACT CGGGTTTGA ACATGTTTT GAGTCCCGG CTACTTGTG GATCTCTGT GATCTCTGT TCCAGTTCT CGATGAGAG TTCTGTGATGG  
 213 K V D K K V E P K S C D K T H G R M K Q L E D K V E L L S K N Y H  
 \*end of heavy chain, start of leucine zipper  
 2101 ACCPAGAGAA TGAAGTGGA AGACTCAAAA AACTGTGCG GGAGCGCGG AAGTTAGTG GCGTGGCTC TGGTTCGGT GATTTTGATT ATGAAAAGAT  
 TGGATCTCTT ACTTCACCGT TCTGAGTTT TTGAACAGCC CCTCGCGCTT TTCGAATCAC GCCCACCAG ACCAAGGCCA CTAACACTAA TACTTTTCTA  
 247 L E N E V A R L K K L V G E R G K L S G G S G S G D F D Y E K M  
 end of leucine zipper, start of gene III coat protein (267-end)  
 2201 GGCAACGCT AATAAGGGG CTATGACCGA AATGCCGAT GAAAGCGC TACAGTCTGA CGCTAAAGC AAACCTTGATT CTGTGCTTAC TGATTACGGT  
 CCGTTTGGGA TTATCCCCC GATCTGGCT TTACGGCTA CTTTGGCGG ATGTCAAGT GCGATTCCG TTGGAACATA GACAGCGATG ACTAATGCCA  
 280 A N A N K G A M T E N A D E N A L Q S D A K G K L D S V A T D Y G  
 2301 GCTGCTATCG ATGGTTTCA TGGTACGTT TCCGGCTTG CTAATGGTAA TGGTGTACT GGTGATTTG CTGGCTCTAA TTCGCAAAATG GGTCAAGTGC  
 CGAGCATAGC TACCAAGTA ACCACTGCAA AGGCGGGAAC GATTACCAAT ACCCAGATGA CCACATAAAC GACCGAGATT AAGGTTTAC CGAGTTCAGC  
 313 A A I D G F I G D V S G L A N G N G A T G D F A G S N S Q M A Q V G  
 2401 GTGAGGTGA TAATTCACCT TTAATGAATA APTTCGGTCA APTTCGGTCA ATATTACCT TCCTCCCTC AATCGGTTGA ATGTCGGCT TTTGTCTTTA GCGTGGTAA  
 CACTGCCACT ATTAAGTGA AATTACTTAT TAAAGCAGT TATAATGGA AGGAGGGAG TTAGCCAACT TACAGCGGGA AACAAGAAAT CCGCACCATT  
 347 D G D N S P L M N N F R Q Y L P S L P Q S V E C R P F V F S A G K  
 2501 ACCATATGAA TTTTCTATTG ATTGTGACAA AATAACTTA TTCCGGTGGT TCTTTGGTT TCTTTTATAT GTTGCCCACT TTATGTATGT ATTTCTTACG  
 TGGTATACCT AAAGATAAC TAACACTGT TTAATTGAAAT AAGGCACCAC AGAAAGCAA AGAAATATA CAACGGTGA AATACATACA TAAAGATGC  
 380 P Y E F S I D C D K I N L F R G V F A F L L Y V A T F M Y V F S T  
 2601 TTGTGTAACA TACTGGGTAA TAAGGAGTCT TAATCATGCC AGTCTTTTG GTTAGCGCG CGATATACCT TGTCTGCCCT CCCGCGTTGC GTCCGCGTGC  
 AACGATTCT ATGACGCATT ATTCCTCAGA ATTAGTACGG TCAAGAAAC CGATCGCGC CGATATACCT TGTCTGCCCT CCCGCGTTGC GTCCGCGTGC  
 413 F A N I L R N K E S O  
 2701 ATGGAGCCGG GCCACTCGA CCTGAATGGA AGCGCGCGC ACCTCGGTAA CGGATTCACC ACTCCAAGAA TTGAGGCCAA TCAATTTCTTG CCGAGAACTG  
 TACCTCGGCC CGGTGGAGT GGACTTACCT TCGCGCCCG TGGAGCGATT GCCTAAGTG TGAGTTCTT AACCTCGGT AGTTAAGAAC GGCCTCTGAC  
 2801 TGAATCGCA AACCAACCTT TGGCAGAACA TATCATTCG GTCCGCCATC TCCAGCAGCC GCAGCGCGC CATCTCGGC AGCTTGGGT CTTGGCCACG  
 ACTTACCGGT TTGGTTGGGA ACGTCTTGT ATAGGTAGCG CAGCGGTAG AGTCTGCGG CGTCCGCCG GTAGAGCCCG TCGCAACCCA GGACCGGTGC  
 2901 GGTGGCGATG ATCGTGTCTC TGTCTGTGAG GACCGGCTA GGTGGCGGT GTTGCCCTTAC TGGTTAGCAG AATGAATCAC CGATAGCGGA GCGAAGCTGA  
 CCACGCGTAC TAGCAGAGG ACAGCAACT CTGGGCCGAT CCGACCGCC CACCGAATG ACCAATCGT TTAATTAGT GCTATGCGT CGCTTGCCT  
 3001 AGCGACTGCT GTCGCAAAAC GTCTGCGACC TGAGCAACAA CATGAATGGT CTTGCGTTTC CGTGTCTTCT AAGTCTGGA AACCGGAAAG TCAGCGCCCT  
 TCCTGACGA CGAGCTTTG CAGACGCTGG ACTGTTGTT GTACTTACCA GAAGCCAAAG GCACAAAGCA TTTCAGACCT TTGCGGCTTC AGTCGCGGGA

FIG. 38C

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3101 GCACCATAT GTTCGGATC TGCATCGCAG GATGTGTGTG GGTACCTCTT GGAACACCTA CATCTGTATT AACGACCGC TGGCATTGAC CCTGAGTGAT  
 CGTGGTAATA CARGCCCTAG ACGTAGCGTC CTACGAGCAG CGATGGGACA CATTGGGAT GTAGACATAA TTGCTTCGGC ACCGTAACTG GGAATCACTA  
 3201 TTTTCTCTGG TCCCGCCGCA TCCATACCGC CAGTTGTTTA CCCTCACAAAC GTTCAGTAA CGGGGATGT TCAATCATCAG TAACCCGAT TAACCCGAT  
 AAAGAGACC AGGCGCGGT AGGTATGGC GTCAACAAAT GGGAGTGTG CAAGTCAAT GGGCCGTACA AGTAGTAGTC ATTGGGCATA GCACCTCGTAG  
 3301 CTCCTCTCTT TCATCGGTAT CATTACCCCC ATGAACAGAA ATTCCCTCTT ACAGGAGGC ATCAAGTGAC CAACAGGAA AAAACCGGCC TTAACATGGC  
 GAGAGAGCAA AGTAGCCATA GTAAATGGGG TACTTGTCTT TAAGGGGAA TGTGCTCCG TAGTTCACAG GTTGTCTCTT TTTTGGCGG AATTGTACCG  
 3401 CCGCTTATC AGAAGCCAGA CATTAAACGT TCTGCAGAA CTCAACGAGC TGGAGCGGA TGAACAGGCA GACATCTGTG AATCGCTTCA CGACACCGT  
 GCGGAAATAG TCTTCGGTCT GTAATTGGCA AGACCTCTTT GAGTGTCTG ACCTGGCCCT ACTTGTCCGT CTGTAGACAC TTAGCGAAGT GCTGGTGCGA  
 3501 GATGAGCTTT ACCGACGAT CCGGAATGT TAAAGTTTA TATTGTGTTA AAATTCGGCT TAAATTTTG TTAATCTCAG TCAATTTTAA ACCAATAGGC  
 CTACTCGAA TGGGTCTCTA GGCCTTAACT ATAAACAAT TTTAAGCGCA AATTAAAC AATTAGTCTG AGTAAACAAAT TGGTTATCCG  
 3601 CGAATCGGC AAATCCCTT ATAAATCAA AGAATAGACC GAGATAGGT TGAATGTTGT TCCAGTTTGG AACAGAGTC CACTATTAAA GAACGTGGAC  
 GCTTAGCCG TTTTAGGAA TATTAGTTT TCTTATCTGG CTCTATCCCA ACTCAACAA AGTCAAAACC TTGTTCTCAG GTGATTAATTT CTTCACCTG  
 3701 TCCAACTCA AAGGCGGAA AACCTCTAT CAGGCTATG GCCACTAGC TGAACATCA CCTAATCAA GTTTTITGGG GTCCAGGTGC CGTAAAGCAC  
 AGTTGTGAGT TTCCCGCTT TTGGCAGATA GTCCGATAC CGGTGATGC ACTTGTAGT GGGATTAGT CAAAACCC CAGCTCCACG GCATTTCTGT  
 3801 TAAATCGAA CCCTAAAGG AGCCCCGAT TTAGAGCTTG AGGGGAAAG CCGGGGAAAG TGGCGAGAAA GGAAGGGAAG AAACGGAAG GAGCGGGCGC  
 ATTAGGCTT GGGATTCCC TCGGGGCTA AATCTGAAC TGCCCTTTTC GGGCGTTCG ACCGCTCTTT CCTTCCCTTC TTTCGCTTTC CTCGCCCCG  
 3901 TAGGGCGTG GCAAGTGTAG CGGTACAGCT CGGCTAAC ACCACACCG CCGCGGTTAA TGGCGCGCTA CAGGGCGGT CCGGATCTCT CCTCGGCGT  
 ATCCCGGAC CGTTACATC GCCAGTGGCA CGCGATTGG TGGTGTGGC GCGCGAAT ACAGCGGAT GTCCCGGCA GGCCTAGGAC GGAGCGCGCA  
 4001 TTCGGTATG ACGTGAAA CCTCTGACAC ATGCACTCC CGGAGACGT CACAGCTGT CTGTAAGCG ATGCCGGGAG CAGACAAGCC GGTCAAGGCG  
 AAGCCACTAC TGCCACTTTT GGAGACTGT TACGTGAGG GCTCTGCCA GTGTGAAAC GACATTCGCC TACGGCCCTC GTCTGTTCGG GCAGTCCCGC  
 4101 CGTCAGCGG TGTTCGGCG TGTTCGGCG CAGCCATGAC CCAGTCACGT ACGATAGCG GAGTGTATAC TGGCTTAACT ATGGCGCATC AGAGCAGATT  
 GCAATCGCCC ACAACCGCC GTCGGTACTG GGTGATGCA TGGCTATCG CTCACATATG ACCGAAATGA TACGCGCTAG TCTCGTCTAA  
 4201 GTATGAGAG TGCACATAT CCGGTGTGAA ATACCGCACA GATGCGTAAG GAGAAATAC CGCATCAGGC GTCTTTCGGC TTCTCGGCTC ACTGACTCGC  
 CATGACTCTC ACGTGTATA GCGCACACTT TATGGCGTGT CTACGCAATC CTCTTTATG GCGTAGTCCG CGAGAACGGC AAGGAGCGAG TGACTGAGCG  
 4301 TGGCTCGGT CGTTCGGCTG GGGCGAGCGG TATCAGCTCA CTCAAAGCGG GTAATACGT TATCCACAGA ATCAGGGGAT AACCGAGGAA AGAATATGTG  
 ACGGAGGCA GCAAGCCGAC GCGCTCGCC ATAGTGGAGT GAGTTTCCG CATATGCCA ATAGTGTCT TACTCCCTTA TTGGTCTCTT TCTTGTACAC  
 4401 AGCAAAAGG CAGCAAAAG CCAGGAACG TAAAAGGCG GGTGTCTG CTTTTTCCA TAGGCTCCG CCGCTGACG AGCATCAAA AAATCGACGC  
 TCGTTTTCG GTCGTTTTC GGTCTTGGC ATTTTTCGG CCAAGAGCC GCAAAAGGT ATCCGAGGCG GGGGAGTCTG TCGTAGTGT TTTAGCTGCG  
 4501 TCAAGTCAAG GGTGCGGAAA CCGGACAGGA CTATAAGAT ACCAGCGGT TCCCTCTGGA AGCTCCCTCG TGGCTCTCTC TGTTCGCGAC CTGCGCTTAA  
 AGTTCACTCT CCACCGCTT GGGTGTCTT GATATTTCTA TGGTCCGCAA AAGGGGACCT TCGAGGAGC ACAGGAGAG ACAAAGGCTG GACGCGGAAT

FIG. 38D

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4601 CCGGATACCT GTCCGCCCTTT CTCCCTCCGG GAAGCGTGGC GCTTCTCAT AGCTCACGCT GTAGGTATCT CAGTTGGGIG TAGTGGTTC GCTCCAAGCT  
 GGCCTATGGA CAGCGGGAAA GAGGGAAGCC CTTCGCACCG CGAAGAGTA TCGAGTGGCA CATCCATAGA GTCAAGCCAC ATCCAGCAG CGAGGTTCCA  
 4701 GGGCTGTGTG CACGAACCCC CCGTTCAGCC CGACCGCTGC GCTTATCCGG GTACTATATG TCTTGAGTCC AACCGGTAA GACACGACTT ATCGCCACTG  
 CCCGNACAC GTGCTGGGG GGCRAAGTCGG GCTGCGCAGG CCGAATAGGC CATGTATAGC AGNACTCAGG TTGGGGCCATT CTGTGCTGAA TAGCGGTGAC  
 4801 GCACGAGCCA CTGGTAAACAG GATTAGCAGA GCGAGGTATG TAGGGGTGTC TACAGATTTC TTGNACTGGT GGCCTAACTA CCGCTACACT AGAAGGACAG  
 CGTCGTCGGT GACCAATTGTC CTAATCGTCT CGCTCCATAC ATCCGCCAG ATGTCTAAG AACTTCACCA CCGGATTGAT CCCGATGTGA TCTTCTCTGC  
 4901 TATTGTGTAT CTGGCTCTG CTGAGCCAG TTACTTCCG AAAAAGAGTT GGTAGTCTTT GATCCGGCAA ACAACACCC GCTGGTAGCG GTGGTTTTTT  
 ATAAACCATA GACCGGAGAC GACTTCGGTC AATGGAAGCC TTTTCTCAA CCATCCAGAA CTAGGCCGTT TGTGTGGTGG CGACCATCGC CACCAAAAAA  
 5001 TGTGTGCAAG CAGCAGATTA CCGCAGAGAA AAAAGATCT CAAGAAGATC CTTGTATCTT TTCTACGGGG TCTGACGCTC AGTGGAAAGCA AAACACACGT  
 ACNAACGTTG GTCGTCTAAT GCGCGTCTTT TTTTCTGHA GTTCTTCTAG GAACTAGAA AAGATGCCCC AGACTGGCAG TCACCTTGCT TTTGAGTGCA  
 5101 TAAGGATTT TGGTCATGAG ATTATCAAAA AGGATCTTCA CCTAGATCCT TTTAAATTAA AAATGAAGTT TTAATCAAT CTAAGATATA TATGAGTAAA  
 ATTCCCTAAA ACCAGTACTC TAATAGTTTT TCCTAGAAGT GGATCTAGGA AAATTAAAT TTTACTTCAA AATTAGTTA GATTTCATAT ATACTCATTT  
 5201 CTTGGTCTGA CAGTACCAA TGCTTAATCA GTGAGCACC TACTCAGCG ATCTGTCTAT TTGCTTCATC CATAGTTGCC TGACTCCCG TCGTGTAGAT  
 GAACGAGACT GTCAATGGTT ACGAATTAGT CACTCGGTGG ATAGAGTCGC TAGACAGATA AAGCAAGTAG GTATCAACGG ACTGAGGGGC AGCACATCTA  
 5301 AACFACGATA CGGGAGGGCT TACCATCTGG CCCAGTGTCT GCAATGATAC CCGGAGACCC ACGCTCACCG GCTCCAGATT TATCAGCAAT AAACAGCCA  
 TTGATGCTAT GCCCTCCGA ATGCTAGACC GGGTCCAGCA CCTTACTATG GCGCTGCGG TCGCAGTGGC CGAGGCTTAA ATAGTCTTAA TTTGGTGGT  
 5401 CCGGAAAGG CCGAGCGCAG AAGTGTCTCT GCAACTTTAT CCGCTCCAT CAGTCTATT AATGTTGCC GGAAGCTAG AGTAAGTAGT TCGCCAGTTA  
 CCGCTTCCC GGTCTCCGTC TTCACCCAGG CATTGAATA GCGGAGGTA GGTCAAGATA TTAACAACGG CCCTTCGATC TCATTCATCA AGCGGTCAAT  
 5501 ATAGTTTGGC CAACTGTGT GCAATCTGCT CAGGATCTGT GGTGTACGC TCGTCTGTTG GTATGGCTTC ATCAGCTCC GGTTCCTAAC GATCAAGGGC  
 TATCAACGC GTTGCAACAA CCGTAACGAC GTCCGTAGCA CCACGTGCG AGCAGCAAA CATACCGAAG TAAGTCGAGG CCAAGGGTTG CTAGTTCCGC  
 5601 AGTTACATGA TCCCCCATGT TGTGCAAAA AGCGGTAGC TCCTTCGGTC CTCCGATCGT TGTCAAGAT AAGTTGGCG CAGTGTATC ACTCATGGTT  
 TCAATGTACT AGGGGTACA ACACGTTTTT TCGCCATCG AGGAAGCCAG GAGCTAGCA ACAGTCTTCA TTCAACCGGC GTCACAAATAG TGAATACCAA  
 5701 ATGGCAGCAC TGCATAATC TCTTACTGTC ATGCCATCCG TAAGATGCTT TTCTGTGACT GGTGAGTACT CAACCAAGTC ATTCTGAGAA TAGTGTATGC  
 TACCGTCCGT ACGTATTAG AGAATGACAG TACGGTAGGC ATTCTAGAA AAGACACTGA CCACTCAGA GTTGTTCTAG TAAGACTCTT ATCACAATAG  
 5801 GCGCACCAG GTGCTCTGC CCGCGCTCAA CAGGGGATAA TACCGGCCCA CATAGCAGAA CTTTAAAGT GCTCATCATT GGAACAGTT CTTCCGGGCG  
 CCGCTGGCTC AACGAGAAG GCGCGAGTT GTGCCATTT GTGCCATCG AGGAAGCCAG GAGCTAGCA ACAGTCTTCA TTCAACCGGC GTCACAAATAG TGAATACCAA  
 5901 AAACTCTCA AGGATCTTAC CGCTGTGAG ATCCAGTTCG ATGTAACCA CTCGTGCACC CAAGTGTCT TCAGATCTT TPACTTTTAC CAGCGTTTCT  
 TTTTGAGAT TCTAGATG GCGCAACTC TAGTCAAGC TACATGGGT GAGCAGCTGG GTTGACTAGA AGTCCTAGAA AATGAAGTG GTCCAAAGA  
 6001 GGTGAGCAA AACAGGAAG GCAATGCC GCAAAAAGG GAATPAGGGC GACACGGAAA TGTGAATAC TCATCTCTT CTTTTTCAA TATTATTGAA  
 CCCACTCGTT TTTGCTCTTC CGTTTTACG CGTTTTTCC CTTATTTCCG CTGTGCTTAT ACAACTTATG AGTATGAGAA GGAATAAGTT ATAATAACTT

FIG. 38E

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6101 GCATTATCA GGGTATTGT CTCATGAGG GATACATATT TGAATGTATT TAGAAAAATA AACAAATAGG GGTTCGCCGC ACATTTCGCC GAAAAGTGCC  
 CGTAAATAGT CCCAATAACA GAGTACTGCG CTATGTATAA ACTTACATAA ATCTTTTAT TTGTTTATCC CCAAGGCGCG TGTAAAGGGG CTTTTACGG  
 6201 ACCGACGTC TAAGAAACCA TTATTATCAT GACATTAACC TATAAAAAATA GCGGTATCAC GAGGCCCTTT CGTCTTCAAT ACAGGTAGAC CTTTCGTAGA  
 TGGACTGCAG ATTCTTTGGT AATAATAGTA CTGTAATTGG ATATTTTAT CCGCATAGTG CTCGGGAAA GCAGAAAGTTA TGTCCATCTG GAAAGCATCT  
 6301 GATGTACAGT GAAATCCCG AANTATACA CATGACTGAA GGAAGGGAGC TGGTCATTCC CTGCGGGGTT ACCTCACCTA ACATCAGTGT TACTTTAAAA  
 CTACATGTCA CTTTAGGGGC TTTAATATGT GTACTGACTT CATTCCCTCG AGCAGTAAGG GACGGGCCAA TGCAGTGGAT TGTAGTGACA ATGAATAATT  
 6401 AAGTTTCCAC TTGACACTTT GATCCCTGAT GGAAGACGA TAATCTGGA CAGTAGAAG GGCCTTCATCA TATCAATGCG AACGTACAAA GAAATAGGGC  
 TTCAAGGTG AACTGTGAAA CTAGGGACTA CCTTTTGGT ATTAGACCTT GTCATCTTTC CCGAAGTAGT ATAGTTTACG TTGCATGTTT CTTTATCCCG  
 6501 TTCTGACCTG TGAAGCAACA GTCAATGGC ATTTGTATAA GACAAACTAT CTCACACATC GACAAACCAA TACAATACAG GTAGACCCTT CGTAGAGATG  
 AAGACTGGAC ACTTCGTTGT CAGTTACCCG TAAACATATT CTGTTTGATA GAGTGTGTAG CTGTTTGGTT AGCTTATGTC CATCTGGAAA GCATCTCTAC  
 6601 TACAGTGAAA TCCCGGAAT TATACACATG ACTGAAGGAA GGGAGCTGCT CATTCCTGCG CCGGTTACGT CACCTAACAT CACGTGTACT TTAATAAAGT  
 ATGTCACCTT AGGGCCTTA ATATGTGTAC TGACTTCCCT CCCTCGAGCA GTAAGGGACG GCCCAATGCA GTGGATTGTA GTGACAAATGA AATTTTTC  
 6701 TTCGACTGA CACTTGTATC CCGTATGGA AACGCATAAT CTGGACAGT AGAAAGGCT TCATCATATC AAATGCAACG TACAAGAAA TAGGGCTTCT  
 AAGGTGAAT GTGAACCTAG GGAATACCTT TTGCGTATTA GACCTGTCA TCTTTCCCGA AGTAGATAG TTACGTTGCG ATGTTTCTTT ATCCGAAGA  
 6801 GACCTGTGNA GCAACGTCA ATGGGCATT GTATAAGACA AACTATCTCA CACATCGACA AACCAATACA ATCTACAGGT AGACCTTTCG TAGAGATGTA  
 CTGGACACTT CGTTGTGAGT TACCGGTAAA CATATCTGTT TGTATAGAGT GTGTAGCTGT TTGTTTATGT TAGATGTCCA TCTGGAAGC ATCTCTACAT  
 6901 CAGTGAATC CCGGAATTA TACACATGAC TGAAGGAAGG GAGCTGTCA TTCCCTGCGG GGTACGTCA CCTAACATCA CTGTACTTTT AAAAAAGTTT  
 GTCACCTTAG GGGCTTTAAT ATGTGTACTG ACTTCCCTTCC CTCGAGCAGT AAGGACGGC CCAATGCGAGT GGAATGTAGT GACAAATGAAA TTTTTCAAA  
 7001 CCACTTGACA CTTTGATCCC TGATGGAAA CGCATATCT GGGACAGTAG AAAGGCTTC ATCATATCAA ATGCAAGGTA CAAAGAAATA GGGCTTCTGA  
 GGTGAAGTGT GAACCTAGGG ACTACCTTTT GCGTATTAGA CCTGTCTATC TTTCGGAG TAGTATAGTT TAGCTTGCAT GTTCTTTTAT CCCGAAGACT  
 7101 CCTGTGAGC AACAGTCAAT GGGCATTTGT ATAGACAAA CTATCTCACA CATCGACAAA CCAATACAAT C  
 GGACACTTCG TTGTCAAGTA CCCGTAAACA TATTCTGTTT GATAGAGTGT GTAGCTGTTT GGTATAGTTA G

FIG. 38F



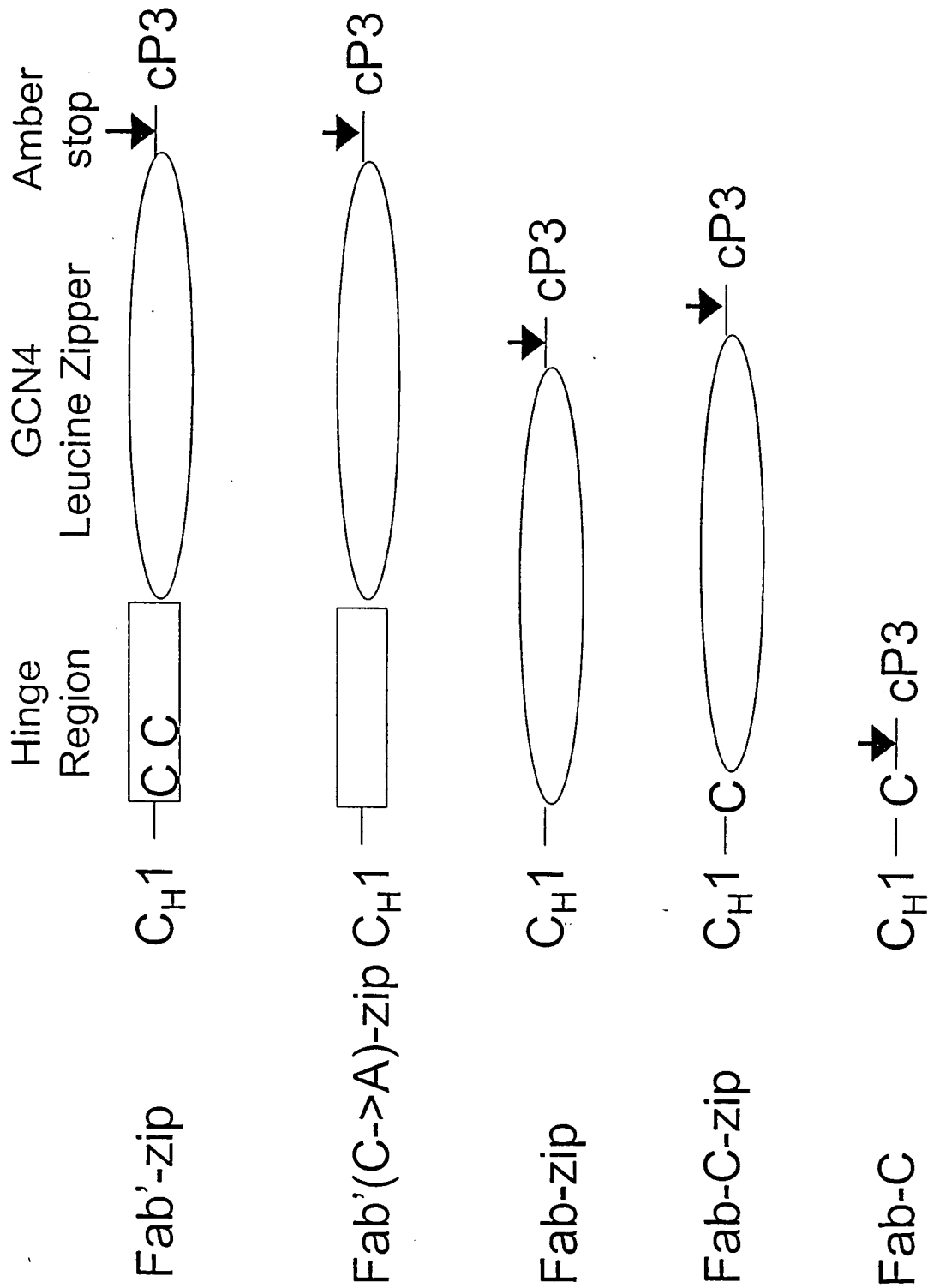


FIG. 39

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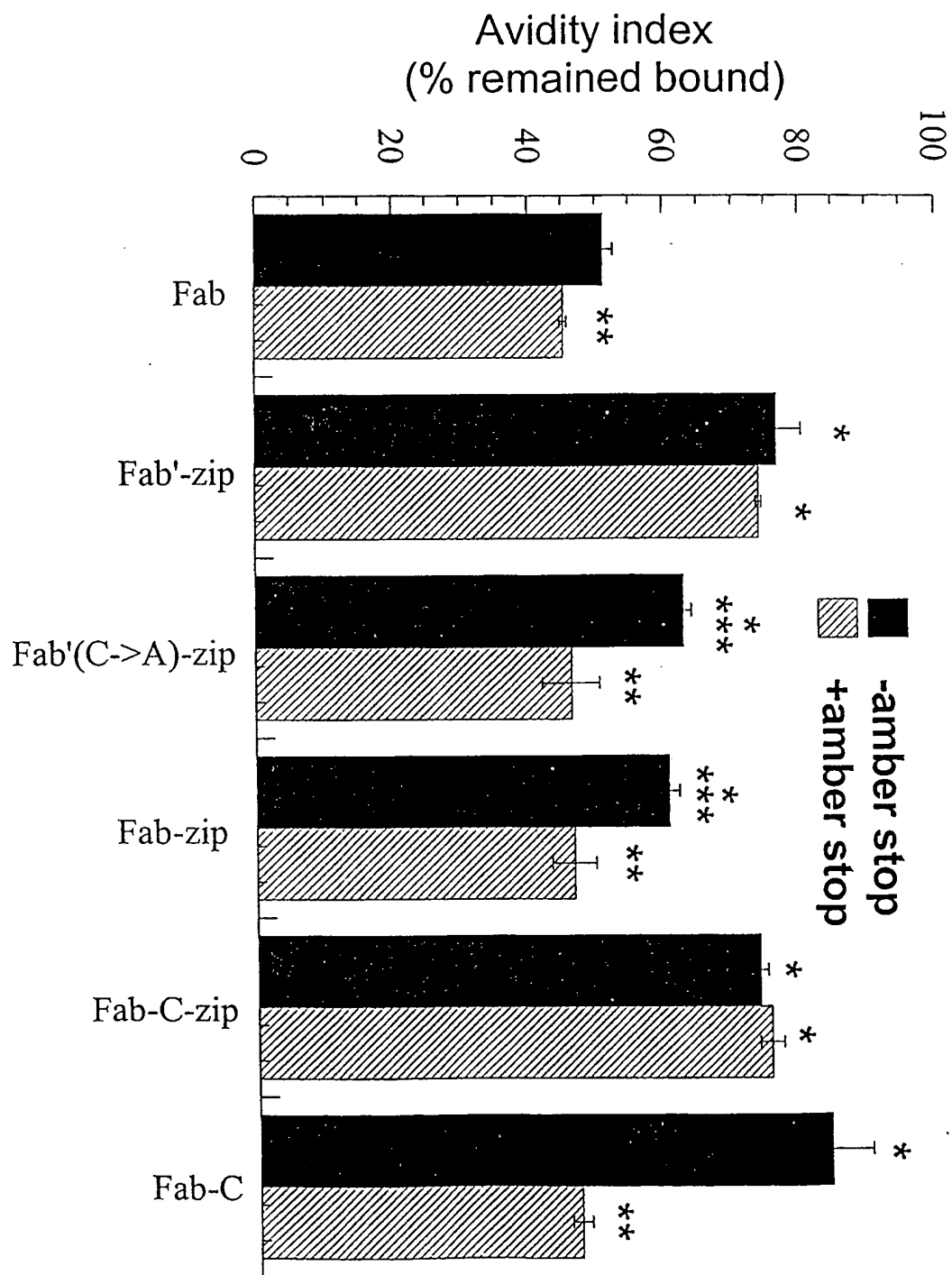
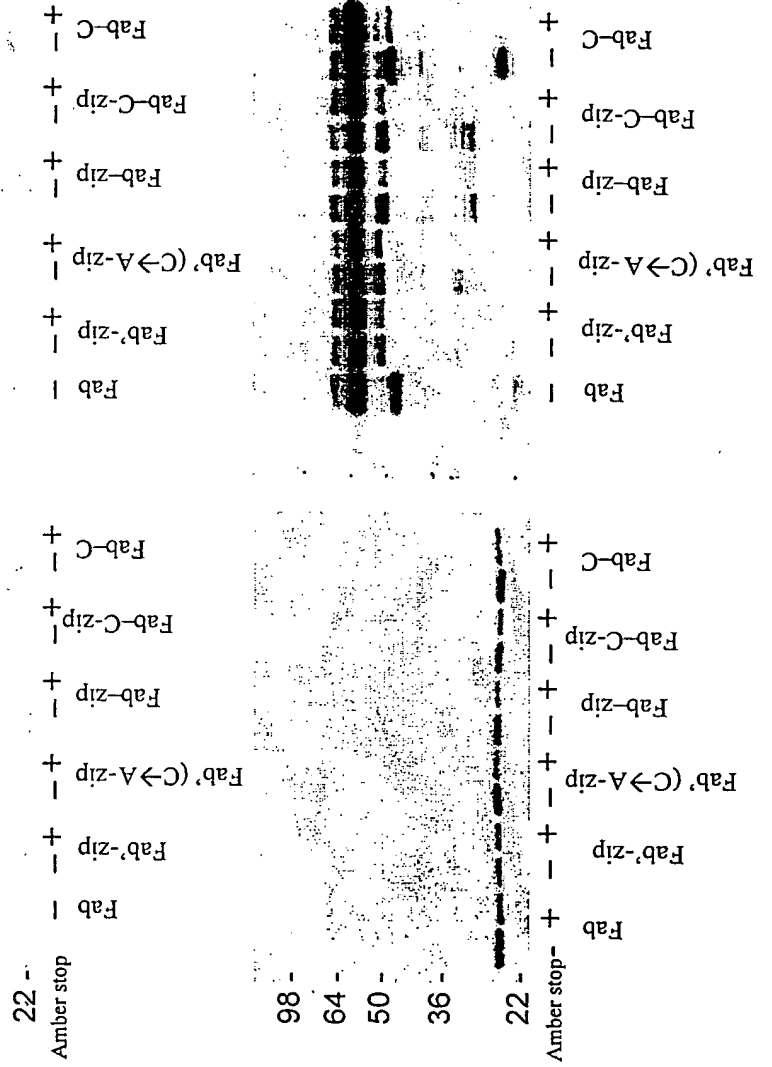
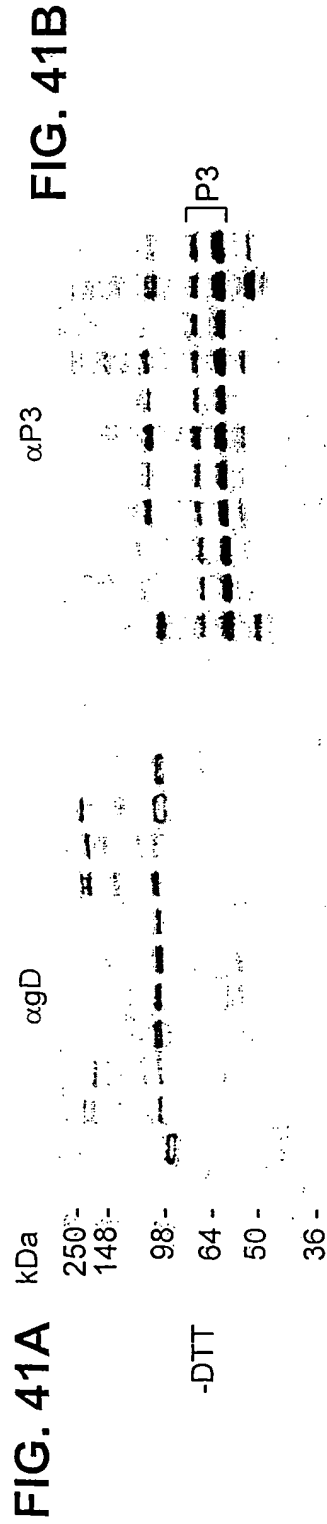
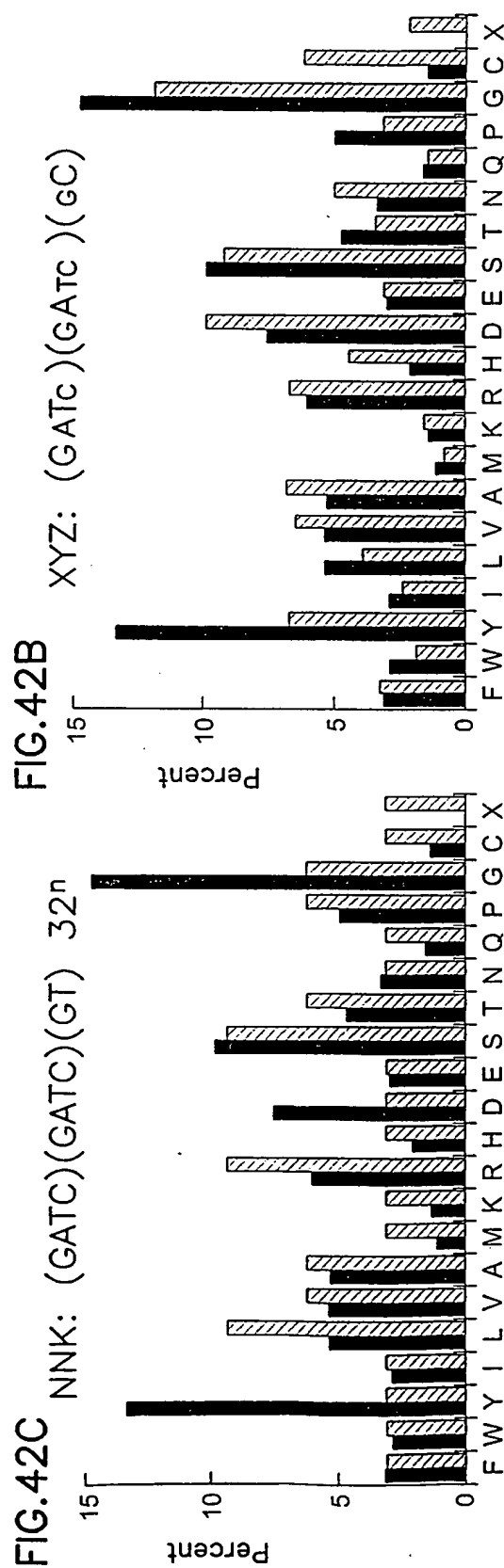
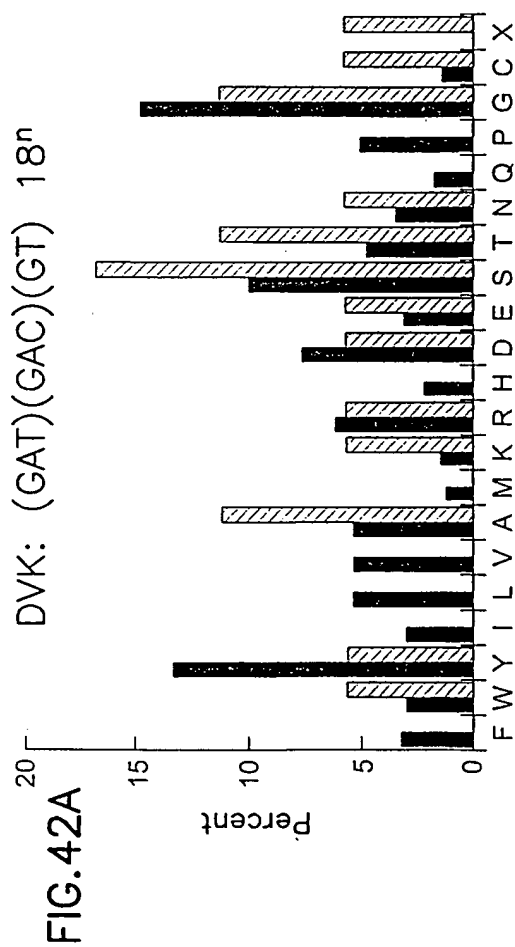


FIG. 40

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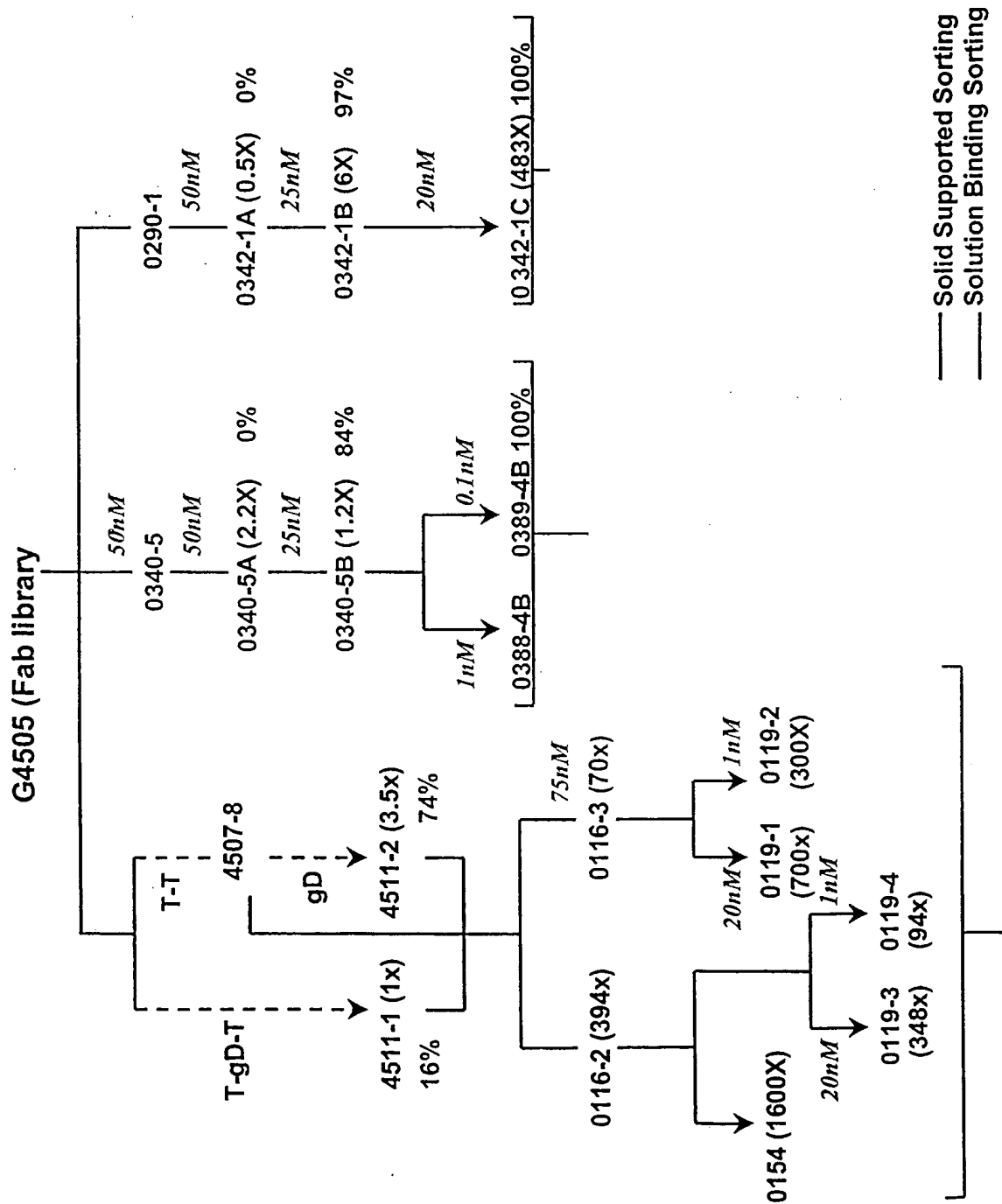


FIG. 44

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## *Two kinds of sorting strategy*

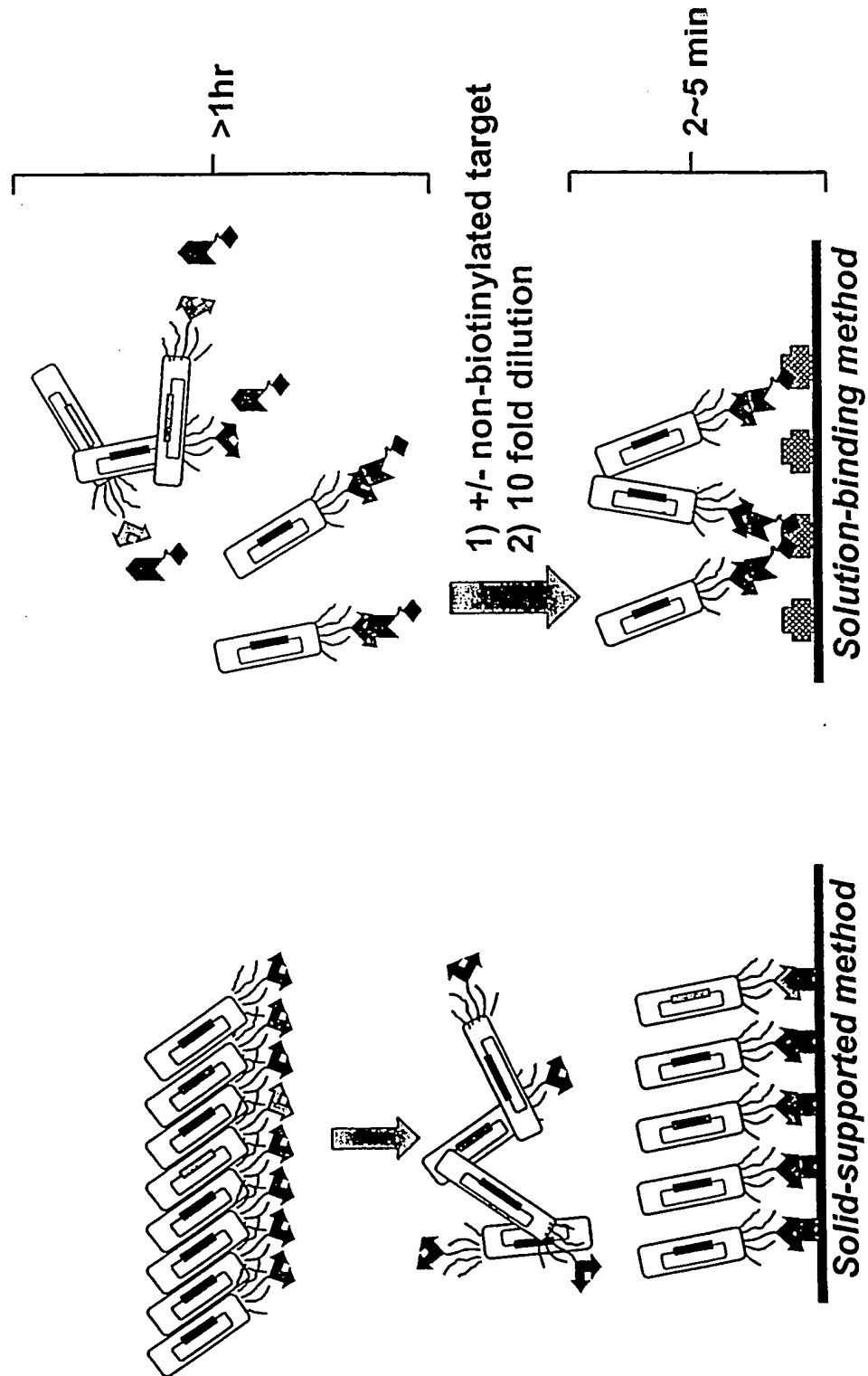
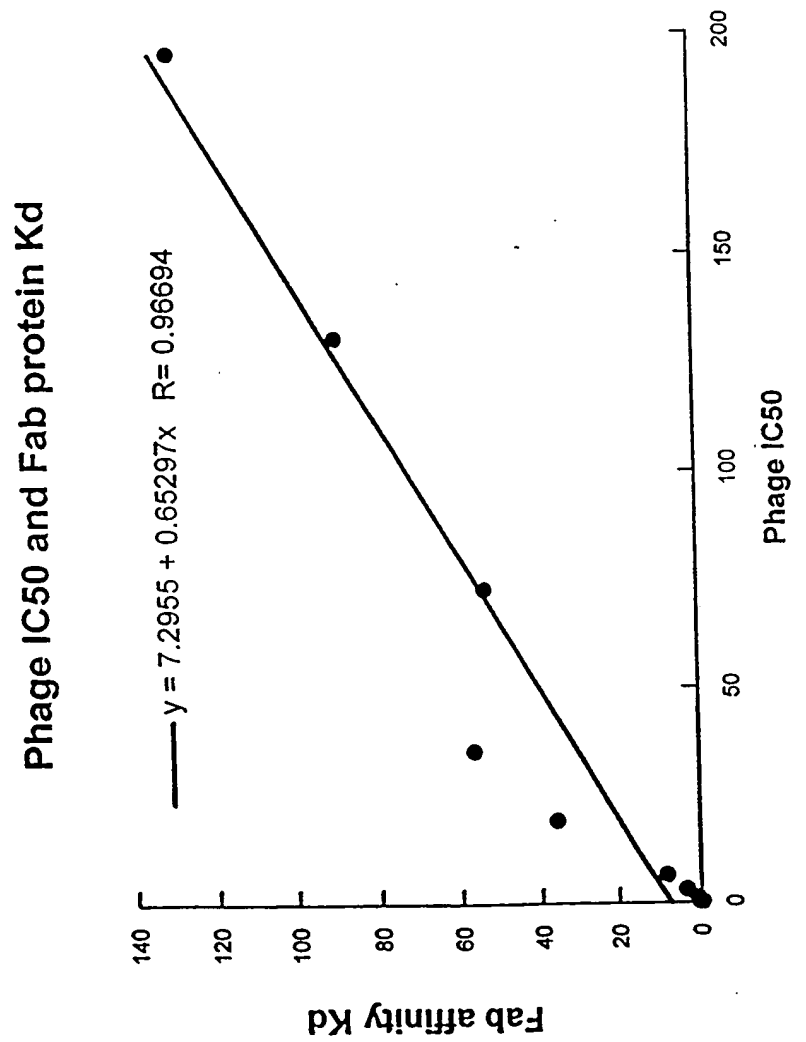


FIG. 45

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**FIG. 46**  
**Phage IC50: reliable as affinity estimates**





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FIG. 47

*Single-spot competition*

Apply 30ul of supernatant of spin  
down cells to plate filled with 25nM  
mVEGF (+) or ELISA buffer (-)



Binding for 1 hour



Transfer 75ul solution  
to plate coated with  
mVEGF(5ug/ml), and binding for  
15min



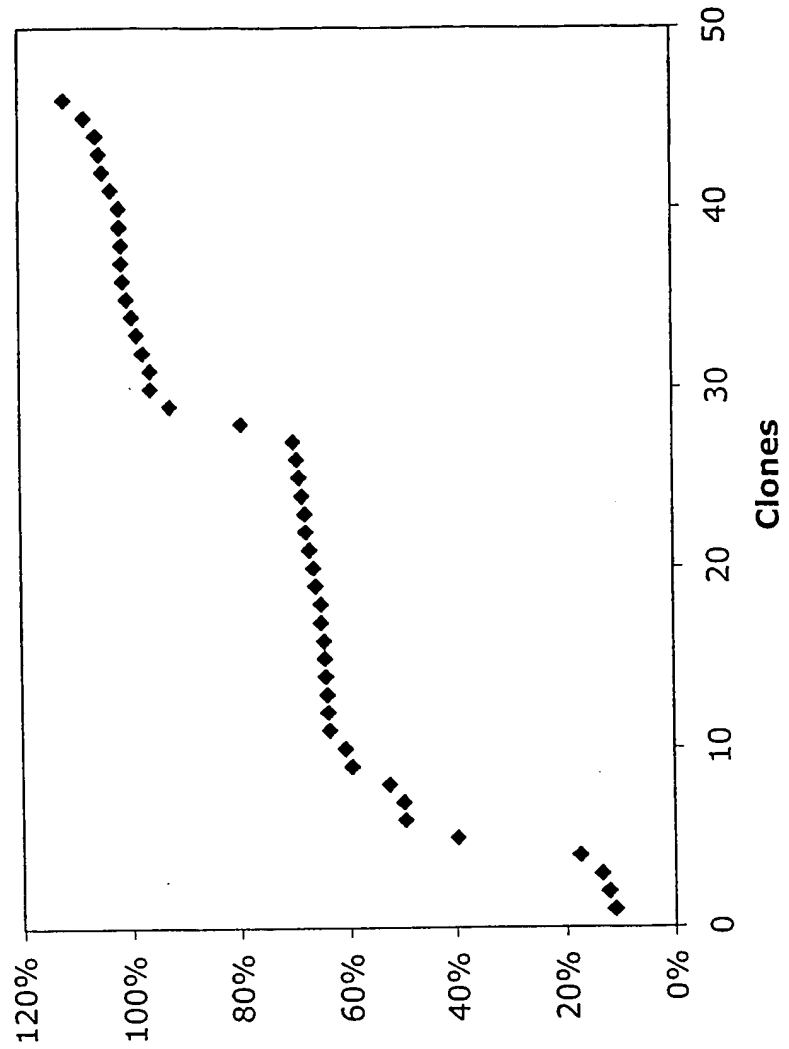
Washing and adding anti-M13-  
HRP



Washing, adding substrate,  
stopping reaction, and reading  
OD at 450nm



Percentage =  $OD_{450} (+) / OD_{450} (-)$



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